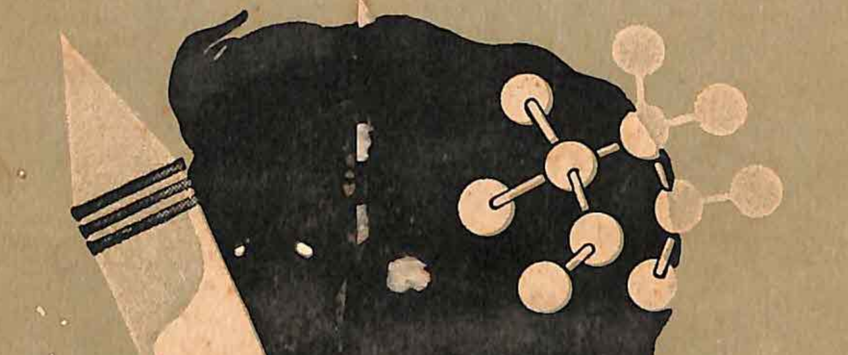
# SCIENCE IN EVERYDAY LIFE

## BOOK THREE



VERSTRAETEN AND WATTS

MANIPUR

STATE INSTITUTE OF EDUCATION
Govt. of West Bengal.

# SCIENCE IN EVERYDAY LIFE

## BOOK THREE

2019

A. VERSTRAETEN, S.J., LIC. ES. SC. (PARIS)
*Principal, St. Xavier's College, Calcutta.*
AND
N. A. WATTS, B.SC., B.T., A.B.T.I.

*With a Foreword by*
A. E. T. BARROW, M.P., B.A., H. DIP. ED., (DUBLIN), T.D.,
*Secretary to the Inter-State Board for Anglo-Indian Education*

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# FOREWORD

As a result of the advances in Science and Technology the vocational foundations of the structure of Society are changing and, therefore, it is essential for all Secondary School pupils to be familiar with certain scientific ideas which underlie progressive thought and activity at all levels.

The purpose of this series of General Science books is to provide such pupils with a broad basic knowledge of scientific facts.

Mere instruction in Science will not capture what is termed the 'spirit of science'. Westaway rightly points out: "The spirit of science cannot be weighed and measured even if weighing and measuring are necessary for tracking it down. It is not enough to track it down, it must be captured........." The authors have succeeded, I believe, in presenting scientific ideas in a manner which will not only instruct but interest pupils and thus help them to capture the spirit of Science.

A. E. T. BARROW

M.P., B.A., H. DIP. ED. (DUBLIN), T.D.,
*Secretary to the Inter-State Board for*
*Anglo-Indian Education,*

and

*Secretary to the Council for the Indian School Certificate*
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# PREFACE

THIS course in General Science is meant to provide the pupils studying in Secondary and Higher Secondary Schools with a scientific outlook; it should make them aware of the impact of science and technology on their natural surroundings and on society.

Besides taking stock of the natural phenomena occuring around them, the pupils should become acquainted with the scientific methods which enable man to acquire an intellectual grasp of these phenomena and put them to use for the benefit and comfort of human society. Only in this way can the citizen of tomorrow be properly trained for the challenge of the complex life of this technological age that is awaiting him.

This is the object of the General Science course prescribed as a Core subject for all pupils studying in Higher Secondary Schools.

The present course is based on, and follows closely, the syllabus of General Science as given in the 'Draft Syllabus for Higher Secondary Schools' issued by the All-India Council of Secondary Education, Government of India, New Delhi.

**The actual break-up and the details of the course are exactly in accordance with the Syllabus in General Science adopted by the Council for the Indian School Certificate Examination and the West Bengal Board of Secondary Education for the schools under their control.**

SCIENCE IN EVERYDAY LIFE is divided into five parts so as to meet the requirements of pupils in schools under the control of the West Bengal Board of Secondary Education studying General Science as a core subject from Class VI to Class X. Furthermore, the series comprises four books to meet the requirements of pupils in schools under the control of the Council for the Indian School Certificate

Examination studying General Science as a core subject from Class (Standard) VII to Class (Standard) X.

The attention of teachers is specially drawn to the item Chapter Activities at the end of every chapter. These should be taken up along with the matter treated in the body of the chapter, as they describe simple experiments illustrating the explanations given in the chapter. Above all, these activities will make the pupils take an active and personal part in exploring their surroundings and acquiring an orderly understanding of the day to day life of the world and the community in which they live.

A. VERSTRAETEN.
N. A. WATTS

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## CHAPTER I

# SIMPLE MACHINES AND HOW THEY WORK

FROM ancient times man has attempted to bend the forces of Nature to his will. In the beginning, he used just a few sources of energy about him, such as wind and water, to help him do his work. He devised machines which were simple in construction and operated by the muscular energy of his fellow men and domesticated animals. But as time went on, his natural curiosity, powers of observation and ability to draw conclusions led him to achieve a greater understanding of his environment. When he made accurate recordings of natural phenomena he set the basis of science.

Through the centuries a vast amount of knowledge accumulated from scientific discoveries. This knowledge has given birth to the modern and scientific world in which we live.

One of the most important steps made in scientific progress during the last two centuries was the discovery of several new sources of energy, the most recent of which is atomic energy. These sources of energy provide modern man with the power to operate machines which enable him to obtain food, warmth, clothing, shelter, speed and convenience in travel, variety in his leisure and, in general, raise his standard of living and comfort.

Before you learn about these sources of energy and how man uses them to run his machines it will be necessary to first understand some simple fundamental ideas.

**Work.** The word 'work' in science has a definite meaning which is sometimes different from the meaning implied in the everyday use of the word. If we attempt to push a house forward there is no doubt that we would not succeed in moving it. If we pushed hard for hours on end we would feel tired. Although we might consider that we have done a great deal of work, yet from a scientific point of view we would not be considered to have done any, since in spite of all our effort the house has remained stationary.

In everyday speech work is considered to be done whenever an object is pushed or pulled; in this consideration, movement of the object is immaterial. In science, however, work is said to be done when some resistance has been overcome and since, in order to overcome a resistance you need to apply force, we may say that work is done when a force acts through a distance. As both these factors, the amount of the force and the distance through which the force acts, can be measured, we can also measure work.

Thus,

$$\text{Work done} = \text{force} \times \text{distance}$$

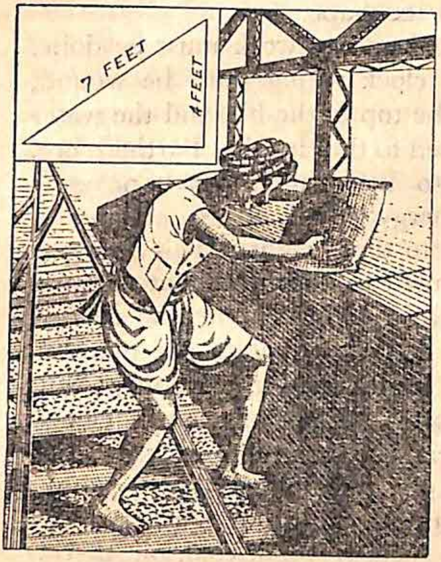
The unit of work is the work done when unit force acts through unit distance against the direction of the resisting force. In the British system of measurement the unit of work, called a foot pound, is the work done in raising a mass of 1 pound through a vertical distance of 1 foot. In the Metric system of measurement the unit of work called the gram centimetre is the work done in raising a mass of 1 gram through a vertical distance of 1 centimetre.

Let us suppose that a bag of coal weighing 100 pounds is raised from the ground to the top of a platform 4 feet above the ground. Since the bag weighs 100 pounds then a force of 100 pounds was required to lift it. The force acted through a vertical distance of 4 feet.

Thus,

$$\begin{aligned}\text{Work done} &= \text{force} \times \text{distance}\\ &= 100 \text{ lb.} \times 4 \text{ ft.}\\ &= 400 \text{ ft. lb.}\end{aligned}$$

If the bag of coal was pushed to the top of the platform up an incline of 7 feet, as shown in the inset of the accompanying illustration, the work done would be the same because though the bag moved a distance of 7 feet, the distance it moved against the direction of the resisting force, that is, the weight of the object, is the vertical distance of 4 feet. It must therefore be remembered that when calculating the work done, the measurement of the distance involved is always against the direction of the resisting force.



*The man is doing* 400 *ft. lb. of work.*

**Energy.** The term 'energy' is used to describe the capacity of any object for doing work. We consider here two main forms of energy. The energy possessed by an object on account of its position is called potential energy, while the energy possessed by an object because of its motion is called kinetic energy. The coiled-up spring of a watch is able to turn the wheels and hands in a watch. Because of its constrained position it possesses potential energy. This energy becomes available while the spring is uncoiling. A rock at the top of a hill possesses potential energy. If the rock is dislodged it rolls down the hill. As it falls it acquires kinetic energy. The water stored behind a dam possesses potential energy. When it is allowed to flow through the dam the energy it possesses is used to do work at an electric power station. Stretching, compressing, bending and twisting a material often causes it to acquire potential energy which becomes available as kinetic energy when the material recovers its shape.

To give an object potential energy work must be done. In the examples cited, the clock spring must be wound, the rock must be raised to the top of the hill and the water behind the dam must be raised to that height. Furthermore, when any object is raised to a certain height it possesses *an amount of potential energy equal to the amount of work expended in raising it to that height.* This potential energy of the body can be used to do an amount of work equal to the work done on it in giving it potential energy. Since the amount of work done is equal to the quantity of energy expended, energy is measured in work units.

Energy exists in many forms. Each of these is closely related to any other and can be transformed from one form into another. For example, green plants absorb radiant energy from the sun's rays and store it up in carbohydrates as available energy. Fuels, such as wood, coal, oil, petroleum and so on, originate from plants. Fuels possess available energy, since the energy stored in them is released by the chemical process of oxidation, it is referred to as chemical energy. When these fuels are oxidised the chemical energy in them is converted into heat energy which can be used to do work. So also, another kind of fuel, the food we obtain from plants, is said to possess chemical energy. When fuel foods are oxidised in the bodies of men and animals, most of the chemical energy in them is converted into muscular energy while the rest is released as heat. These and other forms of energy, such as sound energy, electrical energy and atomic energy, will be further developed in later chapters.

Various sources of energy existed in the world of ancient man very much as they do today. The value of these sources of energy only became apparent when man learned how to convert them into a form which could be utilised for his benefit. In fact, we can say that man had his greatest triumph when he recognised the co-relation of the various forms of energy and how they could be transformed from one form into another. This led him to use each form of energy effectively and in many different ways with great benefits for the advancement and prosperity of civilisation.

**What Makes Work Difficult**? So far you have learned that for work to be done, the force causing the movement of an *object must overcome other forces called resistances.* Three main different kinds of resistance are met with : the resistance of gravity, the resistance of friction and the resistance of inertia.

We already know that the force of gravity pulls everything towards the earth's centre and thus makes it difficult for an object to be raised and moved from place to place.

Another kind of force, called friction, tends to prevent the motion of an object when an attempt is made to move the object over another. This force is located at the point of contact between the surfaces of two objects. It depends on the weight of the object being moved and on the materials of which the surfaces in contact are made. It is a matter of common experience that the heavier an object the greater is the force required to overcome friction and that friction is greater between rough surfaces than between smooth ones. No matter how smooth a surface may appear to be, microscopic examination will reveal that it possesses small irregularities . It is these irregularities which give rise to friction when an object is moved over them and are responsible for causing the object to slow down and finally come to rest. But although we cannot get rid of friction entirely, we can reduce it considerably by a suitable choice of surfaces.

When you try to move an object over another you find that a greater force has to be applied to make it start moving than to maintain its movement. The friction overcome in the first instance is called limiting friction, while the friction overcome in the second instance is called sliding friction. If the object is put on wheels or rollers you still have to exert a greater force to start it moving than to keep it moving. The friction overcome in both instances is called rolling friction and is much less than sliding friction since there is no actual sliding of either surface over the surface of the rollers. Vehicles are placed on wheels and many types of machinery make use of ball-bearings in order to overcome rolling friction rather than sliding friction and thus prevent energy from being wasted. Friction in machines is considerably reduced by lubrication. Oil or grease is placed between two moving surfaces. Besides helping to reduce friction, these materials also prevent the heat that is generated during friction from destroying the machine.

An object at rest tends to remain in this state unless some force from outside acting on it forces it to move. So also a moving object will continue to move in the same direction and at the same speed unless some force from outside acting on it stops it, or changes the direction of its path, or changes its speed. The resistance in all the above cases is possessed by all objects and is called inertia. When an object is at rest, we say that it has the inertia of rest, when it is moving, we say that it has the inertia of motion.

We are all familiar with both these forms of inertia. If you lay an object on a level surface, it remains where you placed it because of the inertia of rest. When you kick a football it leaves your foot and continues moving because of the inertia of motion.

In overcoming friction and inertia a large amount of energy goes to waste. Machines are designed so that the wastage is as small as possible.

**Simple Machines to Make Work Easier.** A simple machine is a contrivance by which the force exerted at a certain point and in a certain direction is rendered available at some other point and in some other direction. It thus enables us to do work more easily and conveniently than with our unaided muscles.

In all the various kinds of machines that are used, the resistance that has to be overcome by the machine is called the load, while the force applied to the machine to overcome the resistance is called the effort. Obviously, the machine which is most effective is that in which a large load is overcome by a small effort.

**Mechanical Advantage.** The multiplication of force obtained by a machine, or in other words, the amount by which work is made easier by the machine is called its mechanical advantage. This is simply a number which expresses the relationship between the resistance overcome by the machine and the force applied to the machine.

Thus,

$$\text{Mechanical Advantage} = \frac{\text{Load}}{\text{Effort}}$$

If the value of the load being moved is less than the effort being applied, the mechanical advantage will be less than 1. This is clearly a disadvantage. In such cases the chief advantage afforded by the machine is in its convenience.

**Efficiency of Machines.** You must not think that the use of a machine saves work from being done. Although the load moved by a machine is very often greater than the force applied to the machine, yet the applied force moves through a greater distance than the load does and thus no work is saved. The question that presents itself is, how does the work we get out of a machine compare with the work we put into it? The measure determining the ratio of the two is called the efficiency of a machine.

$$\text{Efficiency of a machine} = \frac{\text{orWk got out of machine}}{\text{Work put into machine}}$$

Multiplying this by 100, the efficiency is expressed as a percentage.

The work put into a machine is measured by multiplying the effort applied to the machine by the distance the effort moves, while the work got out of the machine is measured by multiplying the load by the distance moved by the load.

No machine exists which is 100 per cent efficient because a large amount of the work we put into it goes to waste in overcoming friction. Thus when we say a machine is 70 per cent efficient we mean that 70 per cent of work is obtained from the machine as was put into it, the remaining 30 per cent being wasted mainly in overcoming friction.

The value of simple machines lies in the fact that although they do not save work yet they are able to perform easily many activities that would otherwise be not only difficult but even impossible. To raise the efficiency of a machine it is necessary to reduce the amount of friction associated with its use. In the ideal frictionless machine we would obtain as much work from the machine as we would put into it. In the machines considered in the pages to follow, the effect of friction is ignored when stating values, as this makes the behaviour of each individual machine easier to understand.

**The Lever.** This is a rigid bar, either straight or curved which is free to turn about a fixed point called the fulcrum. The distances of the effort and the load to the fulcrum are called arms. The law of the lever states that a lever will be in equilibrium when the product obtained by multiplying the load with its distance from the fulcrum is equal to the product obtained by multiplying the effort with its distance from the fulcrum. This law is also known as the Principle of Moments.

Thus,

load × length of load arm = effort × length of effort arm

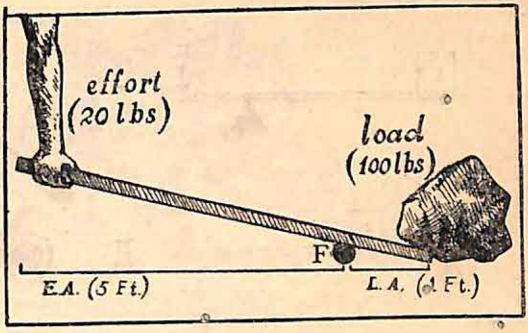
$$\frac{\text{load}}{\text{effort}} = \frac{\text{length of effort arm}}{\text{length of load arm}}$$

or

$$\text{Mechanical advantage} = \frac{\text{length of effort arm}}{\text{length of load arm}}$$

From the above it is clear that, provided the value of the load and its distance from the fulcrum remains constant, we can obtain a greater mechanical advantage by increasing the distance of the effort from the fulcrum.

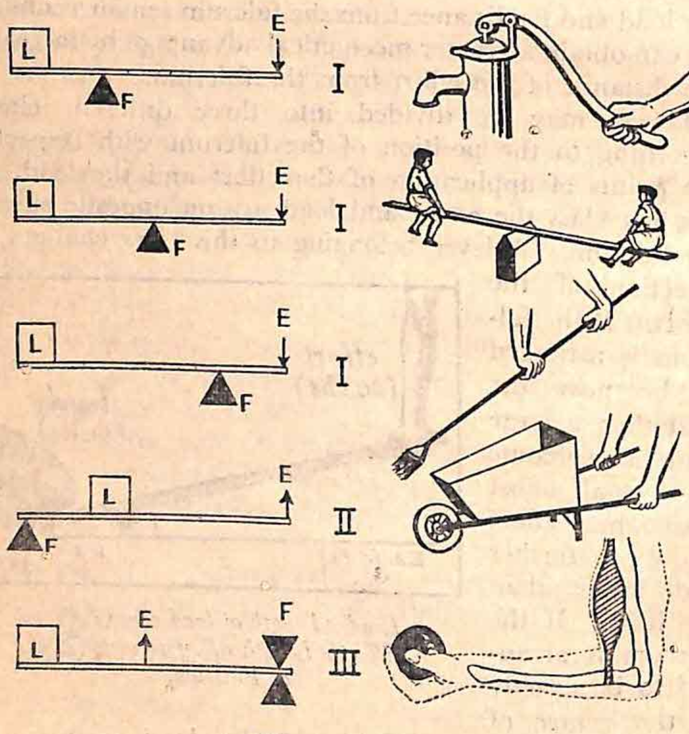
Levers may be divided into three different classes, according to the position of the fulcrum with respect to the points of application of the effort and the load. In the first class the effort and load are on opposite sides of the fulcrum. A lever belonging to this class changes the direction of the effort. If the fulcrum is arranged to be near the load then a large load is overcome by a small effort and the effort moves further and faster than the load. If the fulcrum is arranged to be exactly at the centre of the lever then the magnitude of the load overcome is



*Load × Length of load arm (LA) =*
*Effort × Length of effort arm (EA).*
*F, Fulcrum.*

equal to the magnitude of the effort and the effort moves the same distance and at the same rate as the load. If the fulcrum is arranged to be near the effort, then the effort required is greater than the load and the load moves further and faster than the effort. In all three cases it is seen that the effort gets less the further away it is from the fulcrum. Familiar examples of the first class of lever are the handle of a pump, a see-saw and a broom.

In the second class of lever both effort and load act on the same side of the fulcrum the load being situated between the effort and the fulcrum. A lever belonging

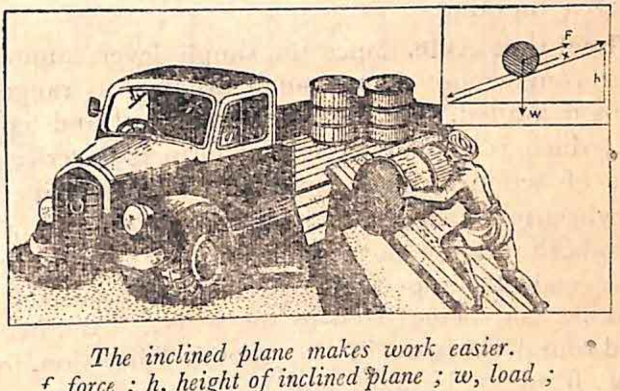


*Classes of levers.*

to this class does not change the direction of the effort. Here the mechanical advantage is greater than unity, that is, the effort required is less than the load, and it moves further and faster than the load. Familiar examples of the second class lever are the wheel-barrow and a pair of nut-crackers.

In the third class of the lever the effort acts between the fulcrum and the load. A lever belonging to this class does not change the direction of the effort. Here the effort required is greater than the load, that is, the mechanical advantage is less than unity. In this class of lever it is the load that moves further and faster than the effort. Familiar examples of the third class of lever are the human arm and a pair of forceps.

**The Inclined Plane.** This is a very simple from of machine generally constructed to lift loads conveniently. It is chiefly used to load and unload heavy objects from a lorry. When used in this way the inclined plane generally takes the form of a plank or platform which is extended from the tail



*The inclined plane makes work easier.*
*f, force ; h, height of inclined plane ; w, load ;*
*x, length of inclined plane.*

end of the lorry to the ground. A load may be too heavy to raise it vertically from the ground to the lorry, but moving it gently along the sloping platform we may be able to raise it to the same height without too much effort. As seen in the figure, by applying a constant force $F$ parallel to the slope we move the load $W$ through a distance $x$ from the ground to the top, the work done is $Fx$, this is equal to the work that would have been done if we raised the load $W$ straight from the ground to the top through a distance $h$, the work done being $Wh$. Therefore, $Fx=Wh$ and the effort required is $F=\frac{h}{x}W$, or a fraction $\frac{h}{x}$ of the weight.

This fraction depends on $x$ which itself depends on the angle of the slope.

The mechanical advantage is $\frac{W}{F}=\frac{x}{h}$.

A sloping road leading to the top of a hill is an example of an inclined plane as is also a staircase leading to the top of a building.

**Wheel and Axle.** Since the simple lever cannot raise a load through more than a small distance its range of usefulness is limited. By means of the wheel and axle, however, which is actually a special form of lever, a greater range of action is made possible. This machine consists of a wheel to which is attached an axle or drum of smaller radius both rotating on the same axis. The effort is applied to one end of a rope which is coiled around the wheel. the other end being fixed to the wheel. Another rope is coiled round the axle in the opposite direction, one end being fixed to the axle, and the free end supporting the load. When the effort is applied, the rope round the wheel uncoils while that round the axle coils up and the load is raised. When the load and effort are balanced, then according to the law of moments we have,

$$\text{load} \times \text{radius of axle} = \text{effort} \times \text{radius of wheel}$$

or,

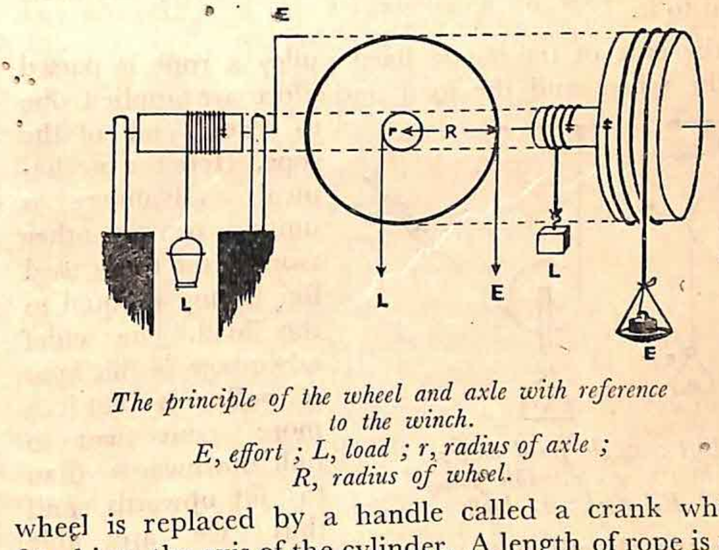
$$\frac{\text{load}}{\text{effort}} = \frac{\text{radius of wheel}}{\text{radius of axle}} = \frac{R}{r}$$

or

$$\text{mechanical advantage} = \frac{\text{radius of wheel}}{\text{radius of axle}}$$

From the above it is clear that the greater the radius of the wheel and the smaller the radius of the axle, the greater is the mechanical advantage.

The winch is an example of a simple machine based on the principle of the wheel and axle. This machine is generally used for raising a bucket of water from a well. Here the axle is in the form of a long cylinder while the wheel is replaced by a handle called a crank which is fitted into the axis of the cylinder. A length of rope is coiled round the cylinder and the load is attached to one end of it. The effort is applied to the handle. Since a crank has replaced the wheel we may say that :



*The principle of the wheel and axle with reference to the winch.*
*E, effort ; L, load ; r, radius of axle ; R, radius of whsel.*

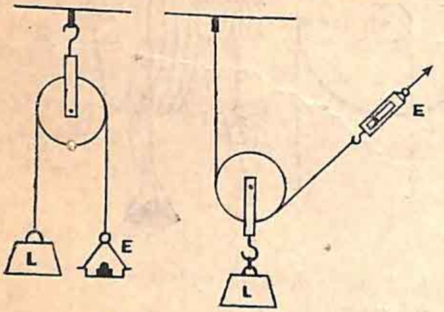
$$\text{mechanical advantage} = \frac{\text{length of handle}}{\text{radius of cylinder}}$$

The capstan and churner are further examples of the wheel and axle.

**The Pulley.** When neither a lever nor an inclined plane will do to lift a large load, a pulley is often used. A pulley consists of a wheel with a grooved rim which rotates freely about an axis (the fulcrum) supported within a framework called a block.

A single fixed pulley operates as a lever of the first class while a movable pulley operates as a lever of the second class. Sometimes several pulleys both fixed and movable are combined together into a system called a block and tackle. Such a device serves to greatly multiply the effort applied to it.

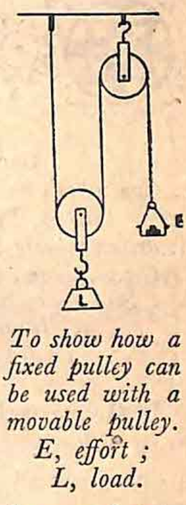
In the case of the single fixed pulley a rope is passed over the wheel and the load and effort are applied one to each end of the rope. Here the mechanical advantage is unity, or in other words, the effort used for lifting is equal to the load. The chief advantage of this kind of pulley is that it is more convenient to pull downwards than to lift upwards and thus we are able to alter the direction of the effort.



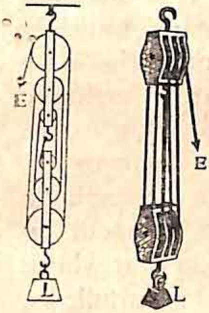
*Left : single fixed pulley.*
*Right : single movable pulley.*
*E, effort ; L, load.*

The movable pulley has all the characteristics of a lever of the second class and is able to multiply the effort applied. Here one end of the rope is attached to a fixed support, while the effort is applied to the other end of the rope. The load is attached at a point just below the fulcrum. In such an arrangement the rope applies two efforts to the load, each acting on either side of the pulley in an upward direction. The effort required to raise the load will now be only half the value of the load as the effect of the effort has been doubled. The value of the mechanical advantage is therefore 2.

Very often a fixed pulley is used in conjunction with a movable pulley. A rope is passed beneath the fulcrum of the movable pulley and over the rim of the fixed pulley as shown. Here also as in the movable pulley the effort required is only half the value of the load. The advantage of this arrangement, lies in the fact that the effort may be applied downwards.



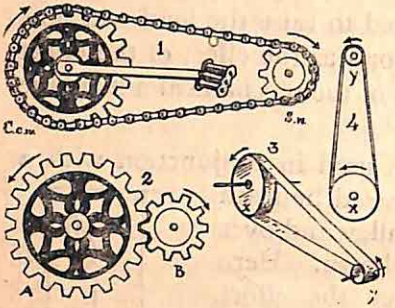
*To show how a fixed pulley can be used with a movable pulley.*
*E, effort ;*
*L, load.*



*Block and Tackle. The diagram on the left shows how the rope is arranged.*
*E, effort ;*
*L, load.*

The system of pulleys known as the block and tackle consists of two blocks each consisting of two or three pulleys, mounted side by side. One block is attached to a fixed support while the other is movable. A rope is attached to a point beneath the fulcrum of the fixed block and is passed around each pulley in turn as shown. The load is attached to a point beneath the fulcrum of the movable block. Each pulley in both the blocks reduces by one-half the effort required to lift the given load. The effort required to lift the load is therefore one-fourth for two pulleys arranged side by side and one-sixth for three and the value of the load and the value of the mechanical advantage is 4 and 6 respectively.

**Gears.** When a driving wheel is joined to a different sized wheel either by a chain or a belt, or is merely brought into contact with the other wheel so that it causes the wheel to rotate in the opposite direction, either at a higher or a lower speed the arrangement is called a gear system. An effort applied to the larger wheel is moved through a much greater distance in one turn of the wheel than the load moves in one turn of the smaller wheel. It is therefore clear that gears multiply force in very much the same way as other simple machines and thus make the work to be done easier.



*Gears.*
1. *Cog wheels and chain.* 2. *Gear wheels.* 3 & 4. *Pulleys and belting.* *A, driven wheel; B, driving wheel; C.c.w., crank chain wheel; S.w., sprocket wheel; X, driving shaft; Y, driven shaft.*

If the wheels are toothed then the size of the teeth on both wheels are the same and the number of teeth on a given wheel is proportional to the diameter of that wheel. The mechanical advantage of the gear system is as follows,

$$\text{mechanical advantage} = \frac{\text{diameter of driving wheel}}{\text{diameter of driven wheel}}$$
$$= \frac{\text{number of teeth on driving wheel}}{\text{number of teeth on driven wheel}}$$

The gear system of a bicycle consists of two toothed wheels connected by a chain. The larger wheel is called the crank chain wheel and the smaller wheel is called the sprocket wheel.

From what we know of the mechanical advantage of the gear system it is clear that if the number of teeth on the crank chain wheel is 20 and the number of teeth on the sprocket wheel is 10 then for one revolution of the crank chain wheel, the sprocket wheel moves through $\frac{10}{20}=2$ revolutions.

Gears are used in factories to transmit power from one shaft to another and to obtain a particular speed of rotation in shafting, also in clocks and watches, bicycle bells, lawn mowers, motor cars, bicycles and so on.

**The Importance of Friction.** Friction is not altogether an evil force. Without friction we should be unable to stand or walk about, but instead we would slip and slide and fall. It is friction that allows nails to hold things together. In order to make use of the force developed by a machine more effectively it is sometimes necessary to increase the friction between some of its moving parts. Brakes are used in many machines for this purpose. Occasionally the wheels of a machine such as a tram begin to slip on the lines, so that transportation becomes impossible. In such cases sand is thrown on the lines to increase the friction and thereby enable the wheels to get a firm hold on the track.

## CHAPTER ACTIVITIES

*Outdoors*

Visit a factory. Note that many of the complex machines that are used are actually modifications and combinations of the simple machines you have studied. Try to recognise the different simple machines used in the construction of complex machines and note the part they play in its working.

*For your wall newspaper*

To what class do the levers that are listed belong? Draw each, pointing out the position of the fulcrum and by means of arrows, show the direction in which the effort is applied and the direction in which the load acts.

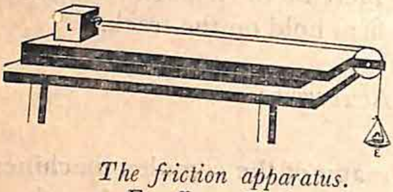
(*a*) A pair of laberatory tongs, (*b*) a tin opener, (*c*) a pair of scissors, (*d*) a pair of bellows, (*e*) a claw-hammer used for extracting nails, (*f*) a bulldog clip, (*g*) a spade, (*h*) a lever of a self-filling fountain pen, (*i*) a balance, (*j*) a bottle opener, (*k*) an oar, (*l*) a pair of pliers, (*m*) a crowbar, (*n*) a pair of coal tongs, (*o*) a door.

*Note-book exercise*

Write an account of the various uses you have seen being made of the following : (*a*) levers, (*b*) inclined plane, (*c*) wheel and axle, (*d*) pulleys, (*e*) gears.

*Laboratory work*

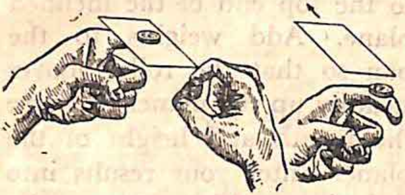
1. Obtain a medium-sized, rectangular block of wood. Fix a screw into one end of the block and place it on a friction apparatus which is merely a folded inclined plane. Attach a string to the hook of the block and tie the other end of the string to a scale pan. Find out what weight must be put on the pan to cause the wooden block to slide. Repeat the experiment with the block placed on a large sheet of sand-paper, a large sheet of glass, on rollers (two pencils) and finally, with a two hundred gram weight placed on the block. In each case note the weight necessary to make the block slide.



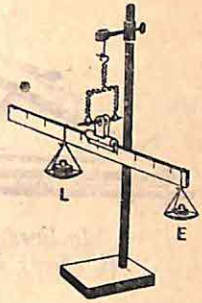
*The friction apparatus.*
*E, effort; L, load.*

2. Arrange a small smooth card and a coin as shown in the illustration. Sharply flick away the card with a

finger. Note that the coin stays on your finger due to its inertia.



*The coin and card trick.*



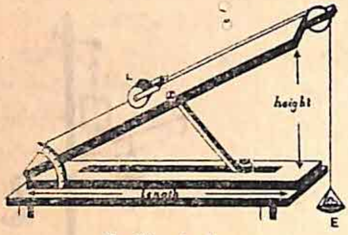
*To show the law of the lever. E, effort; L, load.*

3. Suspend a metre scale at its centre from a retort stand as shown. Hang two different weights on opposite sides of the scale on loops of thin string so that the scale maintains its balance. Measure the distance of each weight from the centre of the scale $A$. Enter your results in the given table. Repeat the experiment with different weights and distances and enter your readings in the table. In each case compare the value of $L \times LA$ with the value $E \times EA$.

| *Load* ($L$) | *Length of load arm* ($LA$) | $L \times LA$ | *Effort* ($E$) | *Length of effort arm* ($EA$) | $E \times EA$ |
|---|---|---|---|---|---|
| | | | | | |

4. For this experiment you will need an apparatus called the inclined plane. Fasten one end of a string to a roller

of known weight and the other end to a scale pan also of known weight. Let the string pass over the pulley attached to the top end of the inclined plane. Add weights to the pan so that the roller moves steadily up the plane. Measure the length and height of the plane. Enter your results into the given table. Repeat the experiment with the plane inclined at different angles and record your results in each case. How does the result in column 3 compare with the result in column 6?



*Inclined plane.*
*E, effort; L, load.*

| *Length of plane* | *Height of plane* | *Length*<br>*Height* | *Effort (scale pan + contents)* | *Load (roller)* | *Load*<br>*Effort* |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| | | | | | |

5. Pass a string over a fixed pulley and tie one end of it to a load of known weight and the other end of it to a scale pan also of known weight, as shown in the illustration on page 14. Add weights to the pan until the load just begins to move upwards. Note the weights you have added. Repeat the experiment with different loads and in each case note the weights that overcome them. Enter your results in the given table.

| *Load* | *Effort* (*scale pan* +*contents*) | $\frac{\textit{Load}}{\textit{Effort}}$ |
|---|---|---|
| | | |

6. Attach one end of a string to a fixed support, pass it under a pulley and tie its other end to the hook of a spring balance as shown in the illustration on page 14. Fasten a load to a point just below the fulcrum of the pulley. Note the effort required to raise the load by reading the spring balance. Repeat the experiments with different loads and in each case record your results in a table similar to that given in No. 5.

7. Arrange a fixed and movable pulley with a load of known weight and a scale pan also of known weight attached as shown in the illustration on page 15. Note the weights that must be added to raise the load. Repeat the experiment with different loads and in each case record the results in a table similar to that given in No. 5.

8. Use a wheel and axle as shown in the illustration on page 13. Measure the radius of the axle and that of the wheel. Attach a load of known weight to the free ends of the string that is attached to the axle and a scale pan of known weight to the string attached to the wheel. Note the weights that must be added to the pan to raise the load. Repeat the experiments with different loads and record your results in the given table.

| *Load* | *Effort* (*scale pan* +*contents*) | $\frac{\textit{Load}}{\textit{Effort}}$ |
|---|---|---|
| | | |

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Compare the results of the third column with the value obtained by dividing the radius of the wheel with that of the axle.

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*At home*

Find out how much you weigh in pounds and then measure the height , in feet, of the top floor of a building above the ground. Multiply your weight with the height of the floor and thus calculate the amount of work you do every time you climb up a staircase leading to the top floor.

## CHAPTER II

## GRAVITATION

ALTHOUGH gravity is a familiar force, it is often misunderstood. Aristotle (384 B.C.-322 B.C.), regarded as one of the greatest of all Greek philosophers, made a study of falling bodies and came to the conclusion (proved later to be erroneous) that the rate at which a body falls is proportional to its weight. Thus, he claimed that if a body weighing 10 pounds was dropped together with an object weighing 1 pound, from the same height and at the same moment, the 10 pound weight would fall 10 times faster than the 1 pound weight. Galileo (1564-1642), the great Italian mathematician and astronomer, extricated from among the many common fallacies of the time the concrete facts which laid the foundations on which scientists of later years worked successfully. He proved that Aristotle's conclusion was false and, re-investigating the whole problem, finally enunciated the law which governs it. He was the first to state that the earth revolves around the sun, and not, as was generally supposed, the reverse. His experiments on the time of swing of a pendulum finally led to a great improvement in the construction of clocks.

Sir Isaac Newton (1642-1727), a famous English mathematician, added results and conclusions of his own to those obtained by Galileo. He was the first to state the laws of gravitation and the laws of motion.

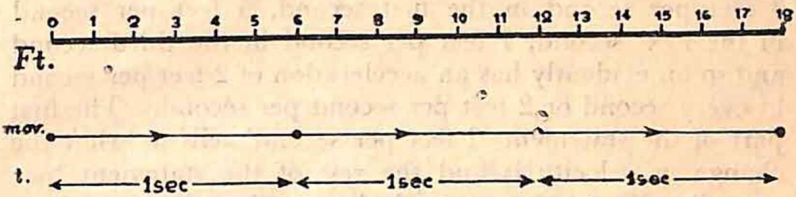
**Speed, Velocity and Acceleration.** Various people such as scientists, engineers, athletes and those concerned with transportation are very interested in speed and its corect measurement. Speed may be defined as the rate at which a body changes its position. The speed of a moving body is measured by the distance travelled in a given time. For example, we speak of a train travelling at a speed of 45 miles per hour. When considering the speed of a body, the question of direction in which the body is moving does not enter and mere reference to the speed of a body implies that its movement is taking place in a constant direction.

Velocity, however, includes a knowledge of the direction in which a body is moving at the particular moment of observation, in addition to its speed. It is defined as the rate at which a body changes its position in a certain direction. Thus, a train may be said to be travelling at a velocity of 45 miles per hour due north. If we consider the motion of a train on a circular track we will note that although its speed is constant, its velocity changes because its direction constantly changes.

The velocity of a body is said to be uniform when it passes over equal distances during equal intervals of time, the direction remaining constant. The velocity of a body is said to be variable when it passes over unequal distances in successive equal intervals of time or changes its direction of motion. Thus, a train has a uniform velocity of 60 miles per hour if it regularly moves a distance of 1 mile in one minute in a constant direction. If a train does not regularly traverse a distance of 1 mile in a minute, but instead halts at stations, then its velocity at the time of leaving a station or reaching it, will be different from its velocity between the stations and so we say that it has a variable velocity.

A body moving in a curved path, such as the hands of a clock, has a constant speed but not a uniform velocity because its direction continually changes. Uniform velocity is measured by the distance travelled in one or other unit of time. A train travelling at a uniform rate and covering a space of 60 feet in 10 seconds has a uniform velocity of $\frac{60}{10}$ or 6 feet per second.

In the case of a body moving with a variable velocity we speak of its average velocity. In this case the total

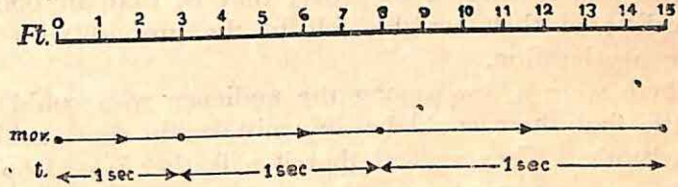


*Uniform velocity.*
*Ft., scale showing feet; mov., movement of body; t, time.*

distance travelled by a body is divided by the time taken to travel this distance. If a train covers a distance of 200 miles in 5 hours including the time spent in stopping at the various stations on its journey then the average velocity is $\frac{200}{5}$ or 40 miles per hour.

Everybody knows that a stone rolling down a hillside does so because it is being pulled downwards by the force of gravity. As it moves it gathers speed and goes faster and faster until it reaches the foot of the hill.

The name given to indicate an increase of speed during successive units of time is acceleration. Properly defined, acceleration is the rate of change of velocity of a body. It may be uniform or variable. A body has uniform acceleration when its velocity changes by equal amounts in equal times and it is measured by the change of velocity produced in unit time. A train which has a velocity of



*Uniform acceleration.*
*Ft., scale showing feet; mov., movement of body; t, time.*

3 feet per second in the first second, 5 feet per second in the next second, 7 feet per second in the third second and so on evidently has an acceleration of 2 feet per second in every second or 2 feet per second per second. The first part of the statement '2 feet per second' tells us what the change in velocity is and the rest of the statement 'per second' tells us the interval during which it takes place. Furthermore, since the increase in velocity is the same every second, the acceleration is said to be uniform.

If the velocity of a body decreases, the acceleration is negative and is known as retardation. Thus, the velocity of a train when approaching a station decreases until it is finally brought to rest.

When a stone is thrown straight up into the air it travels a shorter distance in each successive second or in other words, its velocity decreases and it has retardation. At the moment of reaching the highest point, its velocity is zero. When it begins to fall from this height it travels a greater distance in each successive second, or in other words, it has acceleration.

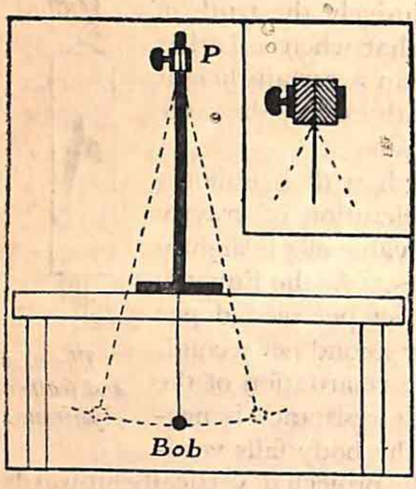
**Acceleration due to Gravity.** When Galileo set about disproving Aristotle's contention about falling bodies, it is said that he climbed to the top of the Leaning Tower of Pisa and before a large audience dropped a 10 pound ball and a 1 pound ball at the same time. When both bodies hit the ground at the same instant many believed what Galileo had attempted to prove, that is, that all bodies, regardless of their weight, fall to the ground with the same acceleration.

There were a few among the audience who could not believe that there could be any mistakes in the teachings of Aristotle. They argued that if a feather was dropped at the same moment as a 10 pound weight, the two objects would certainly not reach the ground at the same instant. Galileo explained that this was because a feather is very large in proportion to its weight and the resistance of the air would act like a brake. Many years later, after the invention of the air pump, Sir Isaac Newton verified conclusively the truth of Galileo's belief. He found that when a feather and a coin were dropped from a certain height in a vacuum they both fell with exactly the same speed.

*The coin and feather experiment.*

All objects fall to the earth with a uniform acceleration, called the acceleration of gravity denoted by the letter *g*. The value of *g* is slightly different for different latitudes. At the Equator the value of *g* is about 32 feet per second per second or 981 centimetres per second per second. In stating the value of *g*, the retardation of the velocity of a body due to air resistance is neglected as it is assumed that the body falls vertically in a vacuum. A body projected vertically upwards loses velocity at the rate of 32 feet per second per second. While falling downwards, the acceleration is positive, and the body gains velocity at the rate of 32 feet per second per second.

**The Simple Pendulum.** You have read in Book I that the time taken by the earth to make one complete rotation about its axis is regarded as a 24-hour day. To tell us when the earth has completed a single rotation, the time is taken from the moment the sun is at its highest point, that is, due South of an observer until it is once again due South of the observer. The interval, called a solar day, is divided into 24 hours, each hour is further divided into 60 minutes and each minute into 60 seconds. For scientific purposes the second is the unit of time. Astronomers determine the true time by the motion of the earth. Their determinations are transmitted to us over the radio by time signals which help us to keep our clocks and watches accurate.

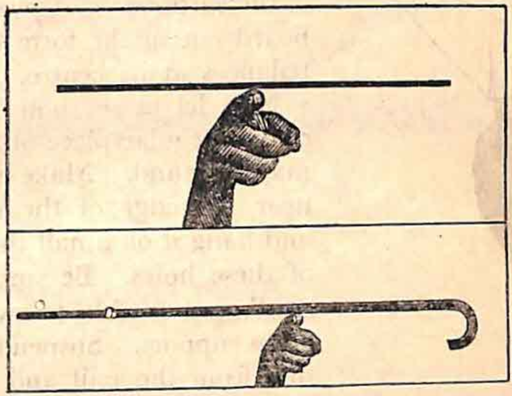


*The simple pendulum.*
*Inset : details of point of suspension (P).*

The pendulum clock is based on the periodic oscillation of a pendulum. A simple pendulum consists of a small but heavy metal ball called a bob suspended by a fine thread from a firm rigid support so that the bob can swing to and fro quite freely. The point of support is called the point of suspension while the distance from this point to the centre of the bob is called the length of the pendulum. When undisturbed the pendulum hangs vertically with the bob pointing to the centre of the earth. If the pendulum is drawn to one side and then released, it swings to and fro and the bob describes an arc. A single swing from one end of the arc to the other is called a vibration. When the bob swings from one end of the arc to the other end and returns to the original side the motion is called an oscillation. Half the distance travelled by the bob between the ends of the arc is called amplitude. The time taken for one complete oscillation is called the period.

It is proved by experiment that the period of a pendulum is independent of the amplitude and the weight of the bob ; the square of the period is directly proportional to the ratio of the length of the pendulum and the gravitational acceleration at a given place ; that means that in order to double the period of oscillation of a pendulum its length must be increased four-fold.

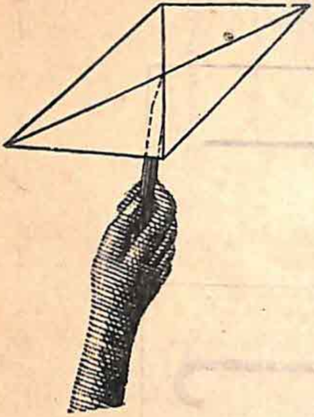
**Centre of Gravity.** If you have ever tried to balance a ruler horizontally on your finger you will know that it will only remain horizontal when supported at the middle. Although every part of the ruler goes up to make its total weight, the weight of the ruler as a whole seems to be acting at the middle. In the case of a walking stick, however, you can only balance it by placing your finger well away from the middle, and it is at a point nearer the handle where the entire weight of the stick appears to be acting.



*A ruler balances when supported at the middle.*
*A walking stick balances when supported at a point nearer its handle.*

No matter what material an object is made of, or whatever its shape, the weight is spread over the whole object. But with everything, the pull of the earth, that is the weight of the object acts as if it were concentrated at a certain point. This point is called the centre of weight or the centre of gravity of the object. If an object is to be balanced on a single support, then the support must be vertically below the centre of gravity.

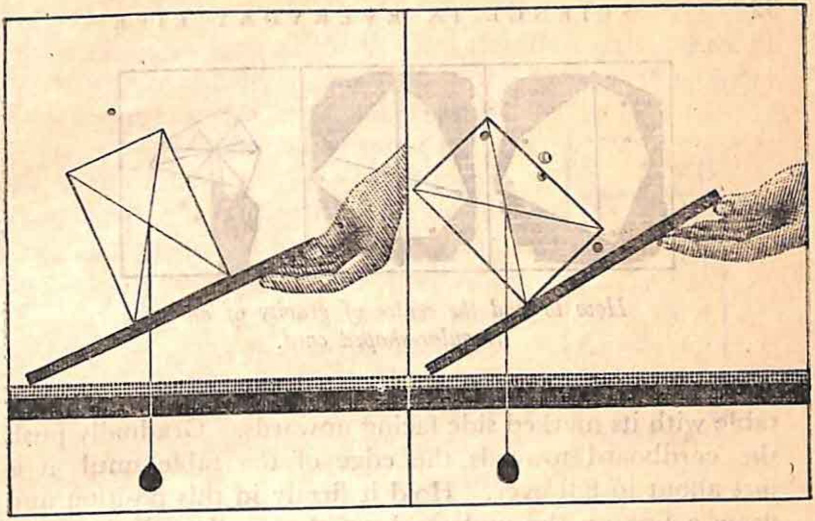
Try to balance a rectangular piece of cardboard on the unsharpened end of a pencil. You will not find it easy. There is, however, a simple method of accomplishing this feat. Draw two diagonal lines on the cardboard. The point where the diagonals cross one another is the centre of gravity of the cardboard. A piece of cardboard cut in the form of a circle balances at its centre.



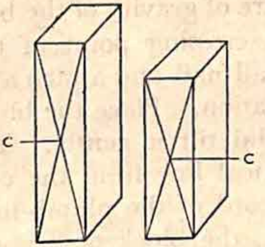
*Balancing a card.*

Now let us see how the centre of an irregular piece of cardboard may be found. Make a few holes near the edge of the cardboard and hang it on a nail through one of these holes. Be sure that the cardboard is able to swing freely on its support. Suspend a plumb-line from the nail and mark the line of the cord on the cardboard. The centre of gravity of the cardboard lies somewhere along the vertical line you have drawn. Suspend the cardboard through one of the other holes and draw another vertical line using your plumb-line to guide you as before. Now the centre of gravity lies somewhere along this second vertical line as well. Two lines have been drawn on the cardboard and the centre of gravity lies on each of them. Obviously, it must be at the point at which the two lines meet. If you suspend the cardboard through each of the other holes in turn and draw vertical lines you will notice that all the vertical lines meet at the same point. Try to balance the cardboard at this point on your finger tip.

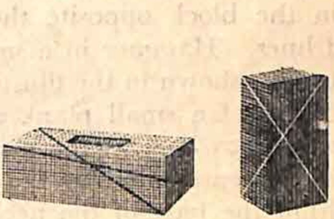
**Stable, Unstable and Neutral Equilibrium.** We will find the answer to this interesting question by using the same irregular shaped piece of cardboard of which the centre of



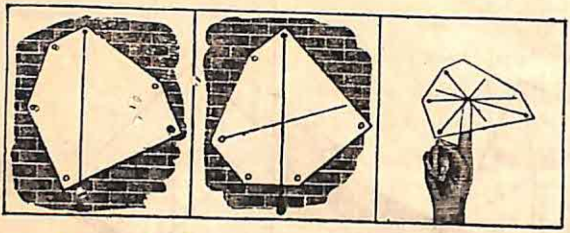
*The block topples over when the vertical line from its centre of gravity passes outside its base.*



*C is a point which is opposite the centre of gravity of each block.*



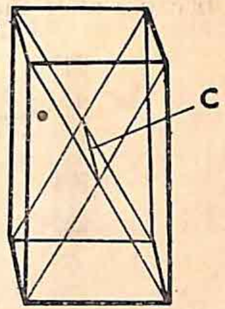
*A brick stands more securely on its broad side than on its end.*



*How to find the centre of gravity of an irregular-shaped card.*

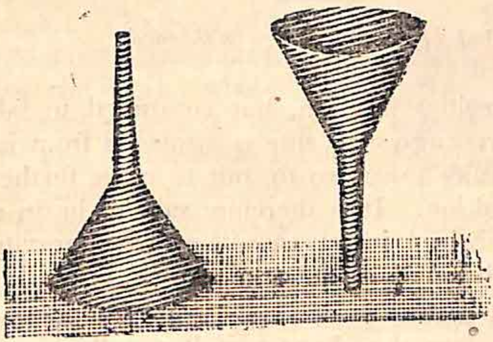
gravity has already been found. Lay the cardboard on a table with its marked side facing upwards. Gradually push the cardboard towards the edge of the table until it is just about to fall over. Hold it firmly in this position and draw a line on the under side of the cardboard along the edge of the table. Change the position of the cardboard and repeat the experiment. Poke a needle through the cardboard at the point where the two lines cross one another. Does this point coincide with the centre of gravity which you have already found on the reverse side of the cardboard ? The experiment you have just done proves that the cardboard over-balances the moment its centre of gravity is no longer supported by the table.

Mark a pair of diagonal lines on one side of a rectangular block of wood. The centre of gravity of the block lies within the block opposite the crossing point of the diagonal lines. Hammer in a small nail and attach a plumb-line to it as shown in the illustration. Place the block near the centre of a small plank and tilt it gently. You will notice that as long as the vertical line from the centre of gravity as represented by the cord of the plumb-line passes within the base of the neck, the block does not topple over. The moment the vertical line from the centre of gravity passes outside the base of the block, the block topples over. This shows that an object will be at rest or balanced as long as the vertical line that passes through its centre of gravity passes within the base of the object. If you repeat this experiment with another rectangular block taller than the first but having a base of the same size, you will find that the angle through which an object has to be tilted before it topples over does not only depend on the area of the base but also on the height of the centre of gravity above the base. A brick stands more securely on its broad side than on its end, its centre of gravity in the first position being lower than in the second position.



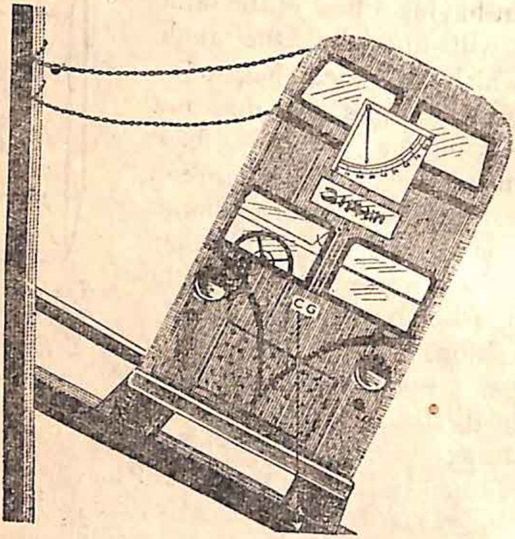
*The centre of gravity of the rectangular block of wood is at point C.*

The lower the centre of gravity of an object and the larger its base, the less likelihood there is of its being knocked over. A funnel resting on the tip of its stem is 'top-heavy', i.e., it is heavily weighted towards the top. In this position the slightest push will send it over. A funnel resting on its mouth cannot be easily pushed over as it is now heavily weighted towards the base and has its centre of gravity towards the base. When given a small push the funnel will move a little and then return to its former position



*A funnel stands more securely on its mouth than on the tip of its stem.*

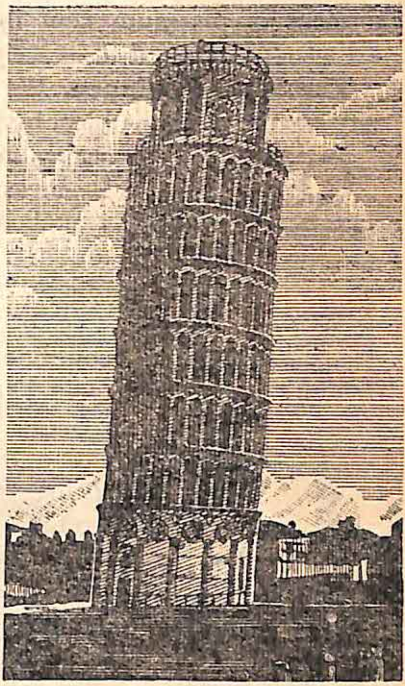
in which case the funnel is said to be in a state of stable equilibrium. In the previous case when a small push sent it toppling over, it was in a state of unstable equilibrium, because after the effect of the small push was over, it did not return to its previous position, but continued to fall down. If a funnel resting on its side is displaced from its position, it tends neither to return to, nor to move further from, its original position. It is therefore said to be in a state of neutral equilibrium, in this case its centre of gravity is neither raised nor lowered by the displacement.



*How a bus is tested before it is driven on the roads.*

A bus is so designed that its centre of gravity is as low as possible and therefore the chances of it toppling over are small. Sandbags equal to the weight of a full load of passengers are loaded into the bus at the right places. The bus is then gradually tilted over to one side. If a vertical line passing through its centre of gravity falls outside its base before it is tilted to an angle of 30° then it is not allowed to be driven on the roads.

You should now be able to understand why so many articles, such as reading-lamps, wine glasses and cake-stands, have a wide base; why we keep our feet apart when standing in a moving bus; why overcrowding is not allowed on the top-deck of a bus and why the Leaning Tower of Pisa does not topple over.

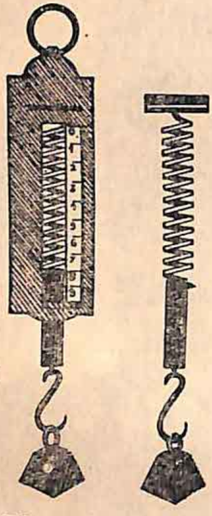

*The Leaning Tower of Pisa.*

**Distinction between Mass and Weight.** What we call the weight of a body is the amount of pull which the earth exerts on the body. When we speak of the quantity of material in a body we are referring to its mass. The mass of a body does not depend on the pull of the earth, whereas the weight of a body does.

The further away a body is removed from the earth the weaker becomes the pull of the earth on it, and though its mass remains the same, its weight decreases. If we should weigh a body at the top of a high mountain it would weigh a little less than at the seaside. Moreover since the earth is not quite spherical but flattened at the poles, a body weighs slightly more at the poles than at the equator.

**Unit of Mass.** In measuring the mass of an object we compare the amount of material in it with the amount of material in some object chosen as the standard. The British unit of mass is called the Imperial standard pound, and is the mass of a piece of platinum kept in London. The Metric unit of mass is the kilogram and is the mass of a piece of platinum kept in Paris. These units of mass are usually referred to as weights.

**The Spring Balance.** We can find out how strongly gravity is pulling on an object by suspending it from a spring and seeing how much the spring stretches. By measuring the amount the spring is stretched we would be measuring the amount of the pull of gravity on the object, i.e. its weight.

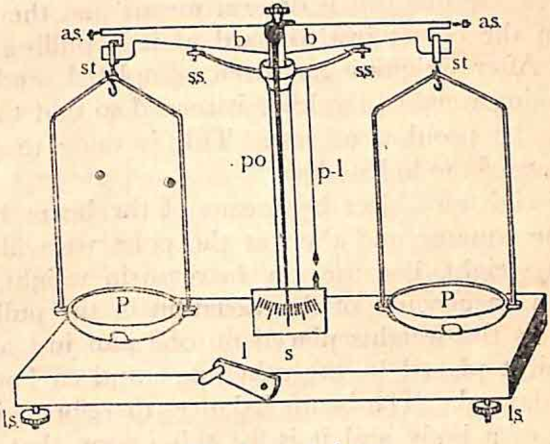

*The spring balance.*

The spring balance consists of a spring contained in a metal case. A pointer attached to the lower end of the spring moves along the scale marked on the case and indicates the amount that the spring stretches. The amount the spring stretches is proportional to the weight of the body extending it. Below the pointer is a bar which carries a hook. Objects for weighing are suspended from the hook, and the extension of the spring is then noted.

The spring balance may be used to show that although the mass of an object remains the same, its weight increases as it is removed from the equator to either of the poles. The difficulty concerning the variation in the weight of an object at different parts of the earth is generally avoided by speaking of the mass of the object instead of its weight.

**The Beam Balance.** If we take two pieces of iron, one having double the mass of the other, we find that the weight of one is also double the weight of the other. At any given place on the earth the weight of an object is proportional to its mass, and objects of equal weight are equal in mass. At any given place therefore we may compare the masses of two objects by weighing them on a beam balance.

The beam balance consists of a beam which is provided at its mid-point with a knife-edge of agate which rests on an agate bed fitted into the pillar of the balance. At each end of the beam a pan is suspended from a stirrup fitted with an agate notch into which fits a knife-edge attached to the beam. The distances from the points of suspension of the pans to the centre knife-edge are equal and the pans are of equal mass. A long pointer is fixed at the centre of the beam and as it oscillates it moves before a scale. At each extremity of the beam there is an adjusting screw to bring the pointer over the zero of the scale if it is not already so. At each corner of the wooden



*The beam balance.*
*a.s., adjusting screws; b, beam; l, lever; l.s., levelling screws; P, pans; po., pointer; p-l., plumb-line; s, scale; s.s., supporting screws; st., stirrups.*

base are levelling screws. These are used in conjunction with the plumb-line suspended by the side of the pillar to ensure that the base is perfectly horizontal so that the beam of the balance is perfectly horizontal when the balance is not loaded.

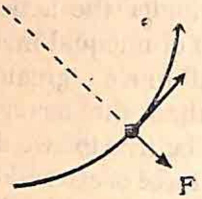
The balance is made ready for use by turning the lever to the left. This raises the beam from the two supporting screws and the pans from the wooden base. The moment the object to be weighed is put on a pan, the pan goes down. Weights are then put on the other pan to restore the balance. When this is done it means that the earth is pulling on the object just as hard as it is pulling on the weights. After weighing has been completed, and whenever changing weights, the lever is turned so that the beam returns to its position of rest. This is done to prevent wearing out of the knife-edges.

If we weigh an object by means of the beam balance, first at the equator and then at the poles we will see no change in weight, because any increase in weight, which is observed on account of the variation in the pull of the earth affects the weights placed on one pan just as much as the object placed in the other pan and so both pans remain balanced. The beam balance, therefore, gives the true mass of a body and it is for this reason that we use it far more than we use the spring balance.

**Gravitational Attraction.** One day when Sir Isaac Newton was relaxing in his orchard he saw an apple falling to the ground. This common incident started a train of thought which finally led him to his discovery of the law of gravitation. He was wondering why an object should always fall towards the centre of the earth and he concluded that there must be a force between the earth and the object tending to pull them together. He then extended his reasoning to the pull between the moon and the earth, and so step by step he arrived at the exact expression of his famous universal law of gravitation. This law states that in the entire universe every object attracts every other object with a force which is inversely proportional to the square of the distance between their centres. The force acting on each of the two bodies is the same, but the greater the mass of a body the slower it moves under the action of a given force, therefore when two bodies of unequal mass attract each other the lighter of the two will move a greater distance in the direction of the other than the heavier one. At first thought this does not seem to be true for we do not see such attraction. This is because the force of attraction is so feeble that the existence of this force cannot be easily demonstrated. An object as large as the earth, however, which is many million times bigger than any object on its surface, pulls everything towards it. The variation with distance, according to this law, means that if the distance between two objects is doubled, the force between the two objects is reduced to one-quarter; if the distance is trebled, the force between the two objects is reduced to one-ninth, and so on. We have already studied the variation with distance in connection with the acceleration due to gravity.

It must be clearly understood that gravitational attraction is not a special property attributed to the earth alone; it is a force of attraction which exists between all objects in the entire universe. All heavenly bodies are pulled towards one another by this force. Since the amount of matter contained in the sun is far greater than that of any of the planets in the solar system, its gravitational attraction is correspondingly greater. It is for this reason that the planets are strongly attracted by the sun. The moon is attracted strongly by the earth because the distance between the two is relatively small. If the above is true you may wonder why the planets do not collide with the sun or the moon with the earth? The answer is that there is another force, called centrifugal force, which eliminates the possibilities of collisions. This force just balances and opposes the gravitational force with the result that the heavenly bodies are kept in their respective orbits.

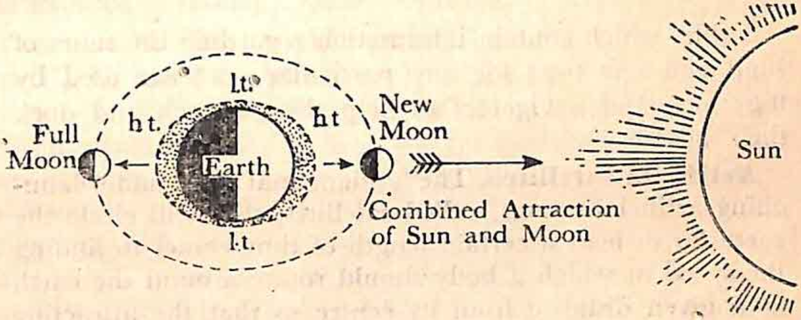
**Centrifugal Force.** This force is well known to people travelling in fast running cars ; it is the force which throws the passengers against the outer side of the car when it turns a corner at full speed. This simply means that the passengers in the car tend to proceed in the straight line in which they were originally moving and hence are pressed against the outer side of the car when it turns a corner. The greater the speed at which the turn takes place and the sharper the turn, the greater the outward force called the centrifugal force, which means a force away from the centre of the curved motion.



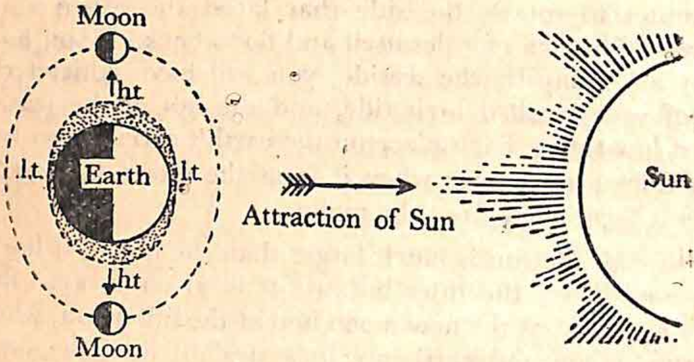
*To show the effect of centrifugal force (F) on a body turning a corner.*

**Tides.** Among all the heavenly bodies the moon is nearest to the earth. Although it is 246,000 miles from the earth and travelling at a sufficient speed to prevent it from colliding with the earth, yet its gravitational attraction does exert a pull on the earth. As the earth rotates about its axis the side facing the moon is continually changing. The side facing the moon is nearer to it than the rest of the earth and therefore the gravitational pull on it is also greater. Since the land is firmly fixed to the core of the earth, the waters of the oceans on that side are pulled more strongly towards the moon and heap up into a hump facing the moon. On the opposite side of the earth there is a similar hump, because there the attractive pull is less than on the rest of the earth, so that the waters are so to say left behind and gather into a hump away from the moon. As the sea is pulled it recedes from the seashore. While the earth continues to rotate, the side that faced the moon turns away and the sea resettles itself and flows back. If you have spent a holiday by the seaside, you will have noticed the rise of water, called high tide, and the fall of the water, called low tide. Each place on the earth's surface gets two high tides a day, once when it faces the moon and again when it faces away from the moon.

Although the sun is much larger than the moon, it has a minor effect on the tides because it is so far away. But twice a month, at the new moon and at the full moon, when the sun, moon and earth are in a straight line, the sun's pull is along the same line as the moon's pull and the two actions are added up so that on these days the tides, called spring tides, are far greater than the ordinary daily tides. When the gravitational pull of the moon acts in a direction at right angles to that of the sun as during the time of the first and the last quarter, particularly small tides, called neap tides, occur.



*The formation of neap tides.*
*h.t., high tides; l.t., low tides.*



*The formation of spring tides.*
*h.t., high tides; l.t., low tides.*

Tables which contain information regarding the times of high and low tides for any particular port are used by fishermen and navigators to help them launch and dock their boats.

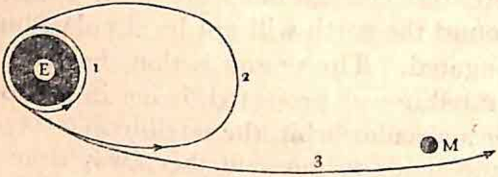
**Artificial Satellites.** The fundamental problem for launching artificial moons, called satellites, that will circle the earth for at least a certain length of time comes to finding the speed at which a body should rotate around the earth at a given distance from its centre so that the attracting force between the two is exactly balanced by the centrifugal force due to the body circling around the earth. There is, however, one particularly disturbing factor and that is the air drag due to the atmosphere surrounding the earth up to very great heights, although the density rapidly decreases with height. In order to minimise the effect of the air drag it is necessary that the prospective satellite should be made to circle the earth at a height of at least 100 miles, or even more, above the surface of the earth. Calculations on the above principles show that for a body to revolve in a circle around the earth, some 250 miles above the surface, it must travel with a speed of 18,000 miles per hour, and it will take about 100 minutes to complete one revolution around the earth.

The practical problem consists of two parts : first to lift the body up to the required height above the earth's surface and then to project it at that height with a speed of 18,000 miles per hour along a direction parallel to the earth's surface. Both steps are usually combined, the body being gradually raised by the propulsive action of a series of rocket motors, the body at first rises vertically, then, by an automatically controlled mechanism, the path of the travelling body is gradually curved so that by the time the required speed is reached, the direction of motion is parallel to the earth's surface and so the artificial satellite proceeds on its circular motion around the earth.

In case the final speed reached is below the required speed, the satellite will fall back on the earth, or burn up when re-entering the denser layers of the atmosphere. In case the final speed is sufficient, but the direction of motion is not parallel to the earth's surface, then also the satellite will return to the earth. If, however, the final speed is higher than the required speed, and even when the direction is not quite the correct one, the path followed by the satellite around the earth will not be circular, but elliptical, that is, elongated. The reason is that the final speed with which the satellite was projected, being in excess of what is required for a circular orbit, the satellite so to say overshoots the mark and tends to move further away from the earth; however, the attracting pull of the earth is gradually bending the path of the fast travelling satellite, so that it still moves around the earth, but in an elliptic orbit.

We spoke of the satellite overshooting the mark when its speed is too great; this leads to the next step, that of launching a satellite with a final speed such that it is able to escape from the gravitational pull of the earth and move further out into space. Scientists have calculated that the 'escape velocity' is 25,000 miles per hour, when the energy of such a fast travelling body will be sufficient to steadily overcome the pull of the earth and move further and further away from it. Naturally as it moves further away from the earth the speed of the travelling body will gradually decrease because of the loss of energy in overcoming the pull of the earth; however, the speed that is left at any time will always be sufficient to overcome the pull of the earth which of course also decreases in intensity as the distance between the two increases.

If on its way this fast travelling body passes close to the moon, it will naturally be attracted by the moon. If it passes very close to the moon, and its speed is now relatively slow, it may land on the moon; if it passes not so close to the moon, yet close enough, or if its speed is not so relatively slow, the pull of the moon may make it turn around the moon as a satellite of the moon; or after turning around the moon it might return to the earth. If, however, it does not pass quite close to the moon, or its speed is too great, then the gravitational pull of the moon will merely bend the path of the satellite which will move on further into space.



*The path of a missile.*
1, *circular orbit*, 2, *elliptical orbit*. 3, *path of missile escaping from the earth's pull.*
*E, earth; M, moon.*

Eventually it will end by turning around the sun in an orbit closely resembling that of the earth's orbit around the sun. The reason is that at the moment the body was launched from the earth, it shared, like all other objects on the earth, the very great speed of the earth in its orbit around the sun, that is some 66,000 miles per hour; adding to this the additional speed which the body still possesses when far out into space after having fully overcome the earth's gravitational pull, it follows that this missile will travel in an orbit around the sun somewhat larger than that of the earth and it will also take more than a year to circle once around the sun.

In case we want to launch a missile that would escape from the gravitational pull of the sun and move on into interstellar space, scientists tell us that the escape velocity from the sun at the distance at which the earth is moving is about 93,000 miles per hour.

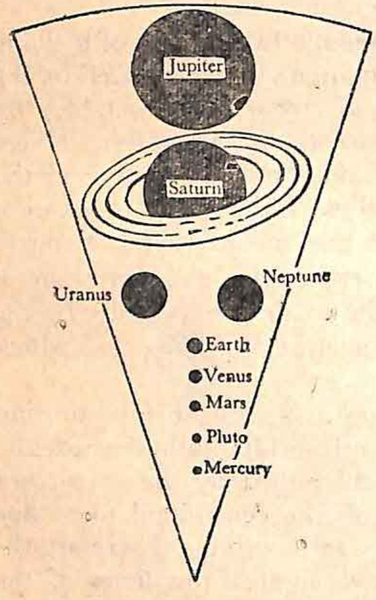
**Sensation of Weightlessness.** In the case of a living being, animal or man, travelling in an artificial satellite, the question arises of the absence of any sense of weight. By weight we mean the pull of the earth on any material object within the space where the gravitational attraction of the earth has an appreciable value, which in fact extends far out into space, since even the moon itself is strongly attracted by the earth. We experience the sensation of weight, that is, of the pull of the earth on our body, by the fact that this force presses us against any object on which we stand or rest.

In the case of a passenger on a satellite turning around the earth in a circular or elliptic orbit, both the satellite and the passenger on it are still pulled by the earth, but this pull is exactly balanced by the centrifugal force due to the movement of the satellite in its orbit. Therefore the passenger is no longer pressed against the floor of the walls of the satellite and experiences no sensation of weight. In fact by merely pressing a finger against the wall he will move in the opposite direction with the greatest ease, in the same manner he could, with the slightest effort move up or down or in any other direction; life in such a space ship should resemble that of a levitation dream. However, a note of caution is necessary: whereas weight is practically absent or nullified, the inertia (mass) of the material bodies remains against the same, and the passenger moving across the space ship by the slightest effort might land against the opposite side with a large impact and with possibly disastrous results.

**Gazing into Space.** In Book I you read that the universe includes the earth and all the other heavenly bodies in existence and that our Solar System is but an infinitesimal unit on the outer rim of a great galaxy or system of stars, known as the Milky Way.

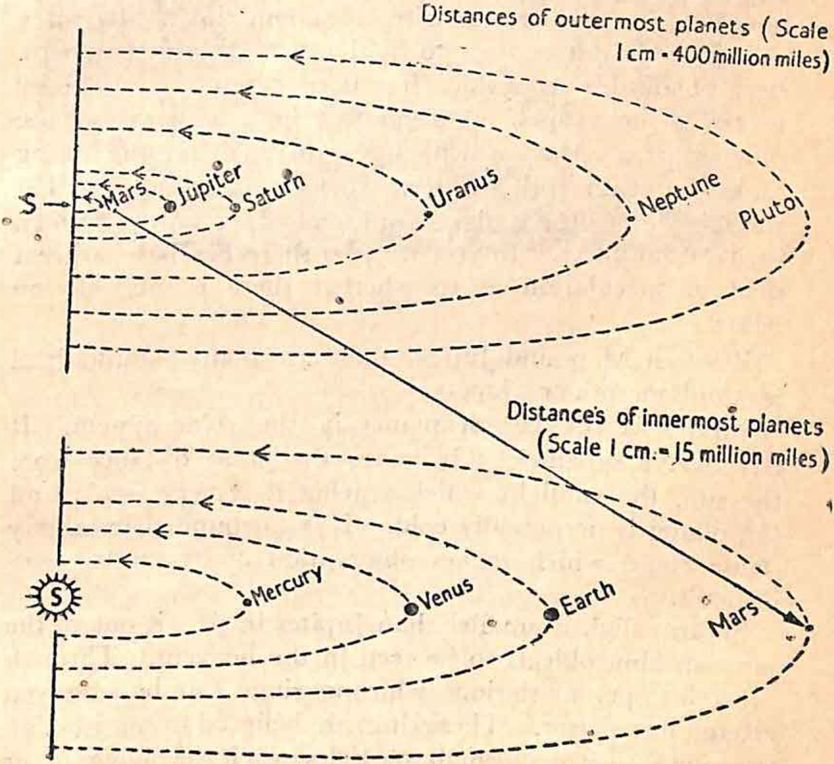
There are nine planets in the solar system: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto.

Mercury is the smallest among the planets and the one nearest the sun. It may be seen sometimes during the hours of twilight and dawn. Since its period of revolution is the same as its period of rotation, it always has the same side facing the sun. One side therefore has perpetual sunshine and is extremely hot, while the other side has perpetual darkness and is intensely cold. This planet has no atmosphere.



*To show the relative sizes of the planets. The triangle represents a 'slice' from the sun.*

Venus is the planet which is nearest the earth. We know that it has an atmosphere, for a powerful telescope shows that it is perpetually surrounded by clouds. Astronomers have been unable to find an opening in the clouds through which they can peer at the surface of the planet. These clouds reflect light excellently. Because of this, Venus appears to be the brightest planet in the sky. You will sometimes see it shining like a little silver lamp close to the sun at sunset. Both Venus and


Distances of outermost planets (Scale 1 cm = 400 million miles)
S
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto
Distances of innermost planets (Scale 1 cm. = 15 million miles)
S
Mercury
Venus
Earth
Mars

*The Sun and the Planets.*

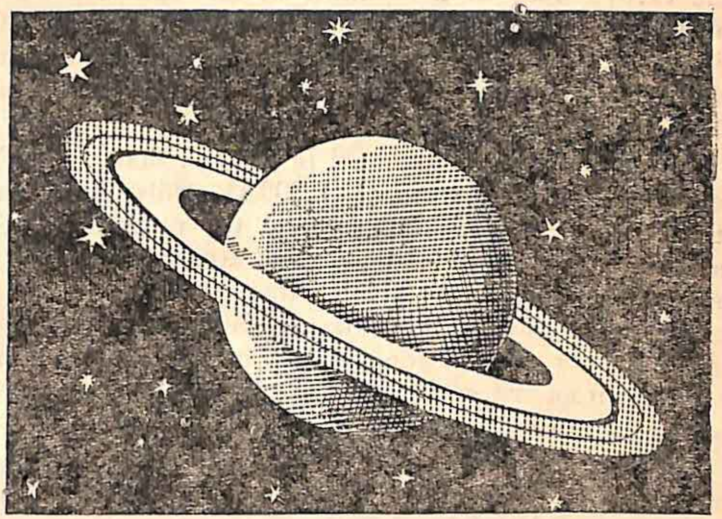
Mercury are the only planets which have their orbits within that of the earth.

The planet Mars may be seen rising in the east at sunset and climbing high into the sky during the night. It is sometimes distinctly reddish in colour. Two satellites, the largest being only about ten miles across, revolve around this planet. Of all the planets in the solar system, Mars is the most interesting because it resembles our own planet in many ways. Like the earth, it is also tilted on its axis and it has days and nights as well as seasons. During the night its temperature is well below 0°C. During the day, however, its temperature rises to about 25°C. Its force of gravity is just enough to hold a very thin atmosphere. Because of this its surface has been carefully studied by means of telescopes. Astronomers have observed white polar caps on Mars which appear to 'melt' in the spring and form again in the winter. It is generally believed that there is water on the planet and a small amount of oxygen in its atmosphere. In recent years there has been a great deal of speculation as to whether there is any life on Mars.

Between Mars and Jupiter there are many thousands of asteroids or minor planets.

Jupiter is the largest planet in the solar system. It has twelve satellites. Owing to the great distance from the sun, the sunlight which reaches it is very weak, and the planet is perpetually cold. It is surrounded by a very dense cloud which makes observation of its surface very difficult.

Saturn, slightly smaller than Jupiter in size, is one of the most striking objects to be seen in the heavens. Through the telescope, mysterious whirling rings can be observed around its equator. These rings are believed to consist of an enormous swarm of small particles, each revolving in its own orbit, those in the inner ring moving at a greater speed than those in the outer one. This planet also has a number of satellites.



*Saturn.*

Uranus and Neptune were discovered in the eighteenth century, whereas the ninth planet in the solar system, called Pluto, was discovered as recently as 1930. These three planets are so far away that they cannot be seen without the use of a telescope.

**The Sun.** Astronomers have been able to determine very accurately the distance from the sun to the earth as about 93 million miles. Knowing also the apparent diameter of the sun's disc, the real diameter is found to be 864,000 miles or 109 times that of the earth, which means that the sun's volume is some 1,331,000 times the earth's volume.

From the speed of revolution of the earth around the sun we know the centrifugal force pulling the earth away from the sun, but, as we know, this is just balanced by the gravitational pull of the sun on the earth. Applying to this case Newton's law of gravitation, and taking the value of the earth's mass as determined in another way by the physicists, it is found that the sun's mass is about 332,000 times that of the earth. Comparing the mass and volume of the sun, its density is found to be only slightly greater than that of water.

We have already mentioned in Book I, that the surface temperature of the sun is about 6,000°C., whilst at the centre it is some 22 million degrees and the pressure there is equal to some ten thousand million atmospheres. This is over a thousand times greater than the pressure at the centre of the earth. The difference is naturally due to the much greater mass of the sun, the pressure at the centre resulting from the gravitational attraction between all the particles constituting that enormous mass of the sun.

Applying Newton's law of gravitation to the movement of the planets around the sun we can likewise determine the masses of the various planets.

While the earth and other planets are turning around the sun, the solar system as a whole is also moving through space, the sun moving steadily towards a particular point in the sky at a speed of 12·5 miles a second so that in one year it moves through a distance of about four times the distance from the sun to the earth.

**The Stars.** When out in the country on a moonless night you gaze at the sky, unspoiled by the glow from the city lights, you are enthralled by the wonderful spectacle of the celestial dome, studded with myriads of glittering spots called stars. You would think that the number of stars you see is truly numberless, yet if you were actually to count them you would find that at any time and from one spot, you cannot see more than about 2,500. Of course people on the opposite side of the earth would see another 2,500 or so, therefore the total number of stars visible to the naked eye is not more than 5,000 to 6,000. If you watch the sky through field glasses, you will discover a much more wonderful spectacle, when about 100,000 stars become visible. And so it was that people started constructing telescopes of ever-increasing power to see fainter stars or stars further out in space, until finally with the help of the modern giant telescopes it is possible to observe several hundred million stars. Of course all these observations are now made mainly by taking photographs, the exposures at times lasting several hours.

By very ingenious methods astronomers have been able to determine the actual distances of quite a large number of stars and nebulae. You will be surprised to learn that outside the solar system, the nearest star is 4½ light years away from us. Since light travels at a speed of 186,000 miles a second, and there are 86,400 seconds in a day, and 365 days in a year, you can easily find the truly astronomical figure representing the distance in miles of our nearest stellar neighbour. Most of the stars, however, are very much further away, the distances of many of them being expressed in millions of light years. The present largest telescope, the 200-inch telescope of Palomar in the United States of America, can observe stars as far away as 2,000 million light years.

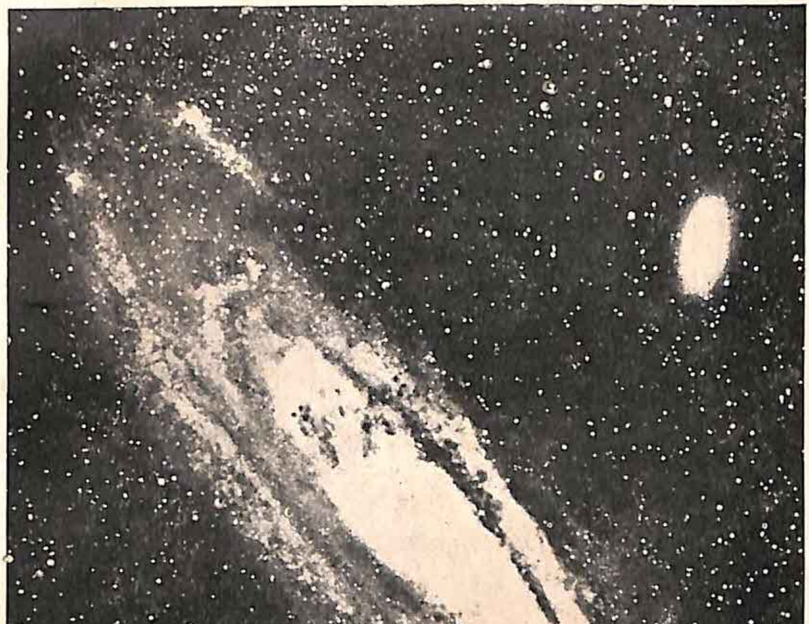
Even when observing with the naked eye we notice the different colours of the stars. There are essentially three types, the bluish-white stars which have a surface temperature varying from 15,000°C. to 30,000°C. and even up to 50,000°C.; the yellow stars, like our own sun, with a surface temperature around 6,000°C.; the red stars, with a surface temperature of about 3,000°C., and then there are the dark stars, with a much lower surface temperature giving off very little light, so that they are only observed as black spots against one or other bright star, these last represent the dying stars of our universe.

Astronomers have also succeeded in determining the sizes of quite a number of stars which are found to vary over a very large scale. Some, called giant stars, are really enormous, for example, the red star Betelgeuse, which has a diameter equal to nearly four times the distance of the sun from the earth. At the other end are dwarf stars, like the companion of Sirius with a size smaller than that of Jupiter, the smallest known star is only the size of the earth but, unlike the earth, it is self-luminous.

To determine the masses of the stars, astronomers applied Newton's law of gravitation to the case of binary stars. These are groups of two stars moving round each other in fixed orbits and in fixed periods, a typical example being that of Sirius and its companion. The results of these measurements and calculations were very interesting and somewhat unexpected. Whereas the sizes of the stars vary from that of the very orbit of the earth around the sun to that of the earth itself, the masses of the stars vary only between one-fifth and twenty times the mass of the sun. This means that in the case of the giant stars the density of their material is exceedingly small, whereas in the case of the dwarf stars it is incredibly large, for the typical white dwarf stars it is 100,000 times that of water.

We must also say a few words about a most remarkable type of stars called variable stars. As we know, our sun appears to be a very steady type of star at least in the present phase of its existence, its brightness being remarkably steady. This is very fortunate for us, because, if the sun's brightness, and consequently the heat received on the earth, were to vary between wide limits, the temperature on earth would also oscillate between extremes of hot and cold and very soon all traces of life would have disappeared from the face of the earth.

There are two quite different types of variable stars, the pulsating and the explosive variables. The pulsating



*The great nebula in Andromeda.*

*The most conspicuous of the star kingdoms in space. Compared with Plate II, also a spiral nebula, this one appears narrow and long because it is viewed nearly sideways.*

PLATE II

*The spiral nebula in the constellation of the Hunting Dogs.*
*It is estimated that the light responsible for this photograph took more than a million years to reach the camera.*

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variables are stars of which the brightness varies periodically between a maximum and a minimum, the periods of variation ranging from an hour to over a thousand days. The explosive variables, or 'novae' as they are called, are stars which increase enormously and very rapidly in brightness, the increase in intrinsic brightness being anything from ten thousand to a million times in one or two days, or in a couple of weeks, after which the brightness subsides, at first rapidly, then more slowly. This looks very much like a stellar explosion, and that is probably what it is since other observations indicate that simultaneously quite a large quantity of gaseous matter is being ejected with great velocity. In our milky way star system some 20 to 30 such stellar bursts take place every year. Then there are the supernovae, corresponding to exceptionally brilliant explosive stars, their brightness reaching up to ten or a hundred million times that of the sun. Such events are very rare, only two supernovae have been definitely observed to occur in our milky way. Tycho's star in 1572, and Kepler's star, in 1604. It is thought that in our milky way such an event should on an average occur only about once in three hundred years. Most probably the bright stars, observed in China in 1054, was a supernovae, its position in the sky is at present occupied by a very large luminous cloud, which may be the result of that explosion. The study of these explosive stars is of the utmost importance with regard to the evolution of the stars.

**The Milky Way—Our Galaxy.** In Book I you have read that since ancient times many of the brighter stars have been arranged in groups called constellations, designated by various and at times rather eccentric names. However, these groupings were made rather arbitrarily and were not based on any scientific principle. Astronomers have naturally endeavoured to find whether the innumerable stars and other celestial bodies observed through powerful

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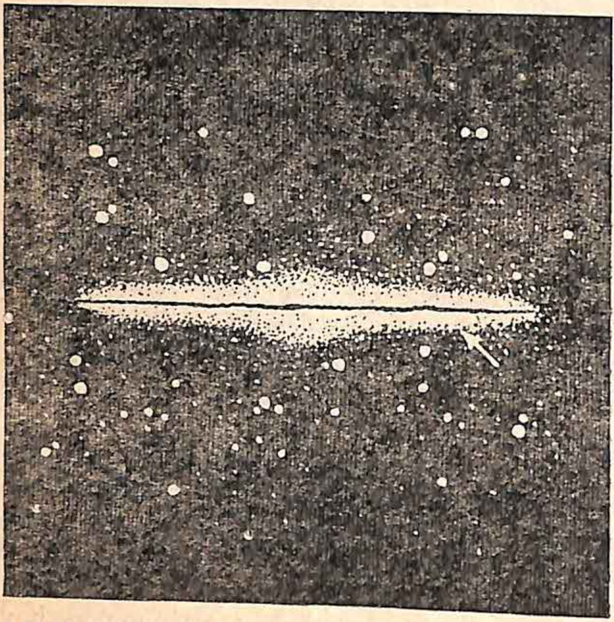
telescopes, are perhaps grouped in some definite manner or other.

There is first of all the obvious and striking appearance of the milky way, that rather narrow belt of a large number of stars stretching right across the sky from one end of the horizon to the other. When the astronomers had determined the positions and distances of many of the stars in the milky way, they discovered that all these stars are grouped in a sort of giant cart-wheel, or, more exactly, a flat giant spiral of about eighty thousand light years in diameter and a thickness of about one-fifth this diameter. The sun is situated about thirty thousand light years away from



*A drawing to show what our galaxy might look like. The arrow points to the approximate position of our solar system.*

the centre, that means rather close to the rim. Naturally when observing from one place near the sun along the main place of the flat spiral we shall observe a rather narrow belt very rich in stars, whereas observing in directions at right angles to this plane the number of stars observed will be relatively small. Such an arrangement of stars is called a galaxy. The number of stars in our galaxy is of the order of one hundred thousand million.

This giant spiral of ours does not stay fixed in space, observations have shown that it majestically rotates about a central axis. The orbital speed of our sun about this axis is about 220 Km. per second; on account of the huge size of this spiral, it will take our solar system about 225 million years to complete one trip around the centre of our galaxy.

If our galaxy is rotating it means that its constituent parts are subjected to centrifugal forces, and these must be balanced by the gravitational attraction between the constituent parts so that the galaxy maintains its shape. Astronomers have applied to this case the universal law of gravitation and have thus succeeded in deriving an expression for the total mass of our galaxy, which comes to about two hundred thousand million times that of the sun.

Apart from the point-like luminous objects, called stars, observed all over the expanse of the milky way, astronomers have also observed quite a number of rather extended luminous patches, like luminous clouds, called planetary nebulae. These are mainly large expansions of gaseous matter rendered luminous by the brilliant light of some associated star or stars.

**Beyond the Milky Way—The Galaxies—The Universe.** The idea that the milky way is a galaxy of stars in the shape of a giant spiral, received strong confirmation when photographs of the sky taken with the help of giant telescopes revealed quite a number of similar aggregations of stars situated far beyond our own galaxy.

When less powerful telescopes were used, only small luminous patches, called nebulae, had been observed, but now it was quite clear that these did not belong to our galaxy and that their constitution was either that of a large spiral, like our own galaxy, or, and more commonly that, of an elliptical shape, like an enormous flat bun. Naturally, their appearance will vary according to the angle at which these giant spiral or elliptical nebulae are seen from our point of observation; if seen edge on, or at full face, or sideways, they will appear as a flat bun or a round disc or a fore-shortened disc or spiral. One of the most beautiful specimens of such a spiral nebulae, is the great spiral of Andromeda, a rather close neighbour of ours.

The sizes of these various galaxies are of the same order as that of our own; their masses are also about the same, although there seem to exist two types, one the heavy-weight galaxies, like our own, the other the light-weight galaxies, about half the mass of those of the first type. Like our own, these galaxies are also rotating about a central axis, and it is from observations of these orbital motions that the values of their masses can be deduced.

The galaxies are more or less uniformly distributed throughout space, as far as the largest giant telescope can see. Another remarkable feature is that observations have shown that all these galaxies are gradually drifting apart and at tremendous speeds, so that, as astronomers put it, the universe itself appears to be continually expanding.

## Chapter Activities

### *Outdoors*

If you have a watch provided with a second hand you can measure the speed of a train. In most parts of our country the mileage is given on the telegraph poles than run alongside the railway track. Generally the telegraph poles are so spaced that twenty four of them make up one mile. Note the time when your compartment passes a telegraph pole and again note the time when it passes the twenty fifth telegraph pole. The difference between the two readings gives the time required for the train to cover a distance of 1 mile. By dividing the distance by the time taken to cover that distance you can obtain the mean speed of the train over a distance of 1 mile.

The acceleration or retardation of a train can also be measured by noting the distance covered by the train in equal successive intervals of time. To measure the acceleration, for example, note the distance covered by the train from the moment of starting, at intervals of say a quarter-minute. The difference between the distance covered in the first quarter-minute and the second quarter-minute gives the increase in velocity during a quarter-minute. From these values the acceleration of the train can be calculated.

### *For your wall newspaper*

Make large labelled drawings of all the various kinds of weighing machines used in your town.

### *Note-book exercise*

Write an account of the most recent developments in the exploration of space.

### *Laboratory work*

1. Set up a simple pendulum by fixing one end of a length of thread between two flat pieces of cork held together in the wooden clamp of a retort stand and tying the other end of the thread to a metal bob as shown in the illustration on page 28. Place the retort stand at the edge of

a table so that the clamp projects over the edge. Adjust the length of the pendulum to about 1 metre. Move the bob to the right and start the pendulum swinging.

Note when the pendulum, moving towards the right, passes the line $OX$ and when next it passes the line, moving in the same direction. This is counted as one oscillation. By means of a stop-watch note the time taken by the pendulum to make 20 oscillations and hence calculate the period of the pendulum. Repeat the experiment several times in each case increasing the amplitude. What do your observations tell you about the relationship between the period of the pendulum and the amplitude?

2. Repeat No. 1 using bobs of different masses and find out the relationship between the period of the pendulum and the mass of the bob.

3. Repeat No. 1, using the same bob and the same amplitude but varying the length of the pendulum for each repetition of the experiment. Enter your results in a table such as the one below:

| *Length of pendulum* (*cm.*) | *Time of* 20 *oscillations* (*sec.*) | *Period* $\left(\frac{Time}{20}\right)$ | *Length* (*cm.*) | $\frac{(Period)}{Length}$ |
|---|---|---|---|---|
| | | | | |

What inference can you draw from the values in the last column?

*At home*

The centre of gravity can be made to lie in unexpected places by the appropriate use of heavy substances. Do these tricks and make these toys to puzzle your friends.

1. If you try to balance a cork on the point of a pencil you will find it very difficult to keep the vertical line through the centre of gravity of the cork going through such a small

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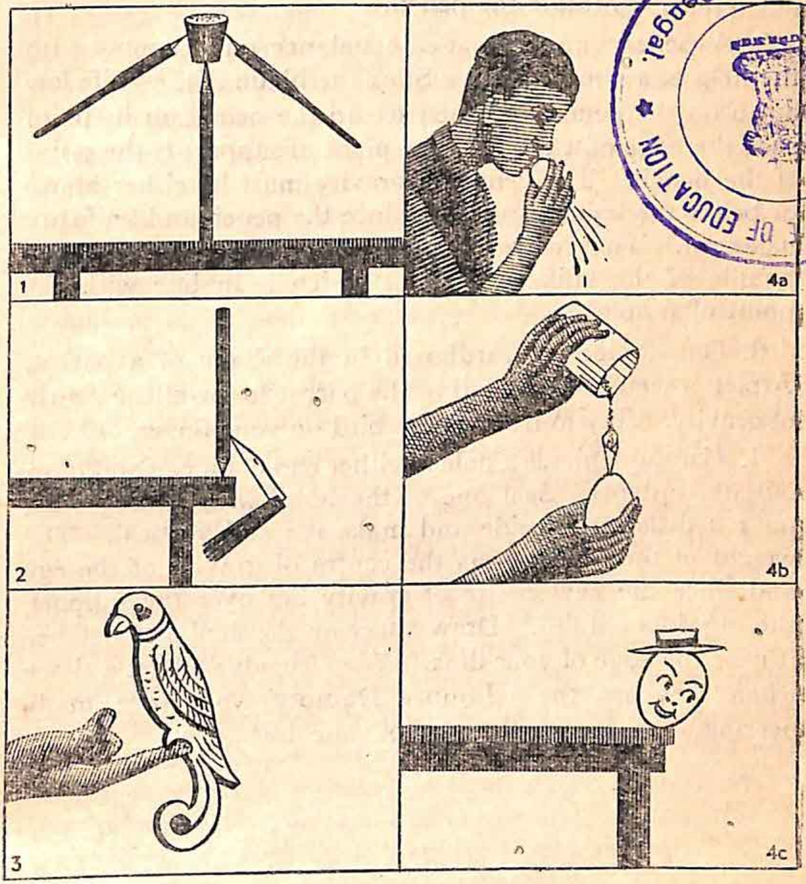


*Centre-of-gravity tricks and toys.*
1. *Balancing a cork on the point of a pencil.* 2. *Balancing a pencil on its point.* 3. *The balancing parrot.* 4(a). *Blowing out the contents of an egg.* 4(b). *Pouring sand into the egg.* 4(c). *The completed 'Humpty Dumpty'.*

point of support. By sticking two pens slanting downwards into either side of the cork the centre of gravity of the balancing objects will be lowered because of the weight of the pens. The centre of gravity is now below the point of support, i.e. inside the pencil.

2. A pencil can be made to balance on its point with the help of a pocket knife. Stick the blade of the knife low down on the pencil and then set up the pencil on its point near the edge of a table. The point of support is the point of the pencil. The centre of gravity must lie either above or below the point of support, since the pencil and knife are balanced. The centre of gravity is situated in the heavy handle of the knife at a point which is in line with the point of support.

3. Cut a piece of cardboard in the shape of a parrot. Attach a weight to the tail of the parrot to lower the centre of gravity. Try to balance the bird on your finger.

4. Carefully pierce a hole at either end of an egg and blow out its contents. Seal one of the holes with sealing wax, pour a little sand inside and make it stand vertical. The weight of the sand lowers the centre of gravity of the egg and since the new centre of gravity lies over the support, the egg does not fall. Draw a face on the shell and balance it near the edge of your desk. Your friends will get a shock when they see the 'Humpty Dumpty' you have made peering at them over the edge of your desk.

## CHAPTER III

# LIGHT IN OUR LIVES

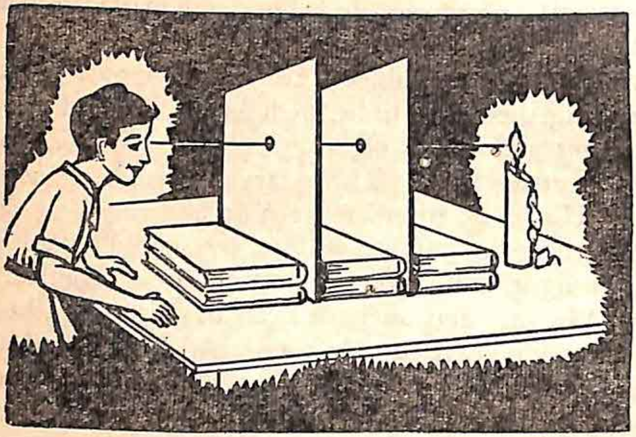
HAVE you ever thought about the way you are able to see persons and objects around you? This requires essentially two things: light proceeding from the different points of the object towards you, and the eye receiving this light and transforming it into a small image of the object at the back of the eye.

In this chapter we shall explain how the light from the object reaches your eye and how the eye transforms it into an image.

As you know, some objects are self-luminous, producing and emitting their own light, such as the sun and the stars, the burning gas in the oil lamp, or the glowing filament in the electric bulb. These are referred to as light sources. However, most of the objects around us become visible by borrowed light, that is, by sending back in all directions light falling on them from one or other light source. We say that such objects are diffusing the light falling on them, and in this way we distinguish this case from the other one in which, when light falls on a smooth polished surface, it is reflected in one particular direction, as you well know from the way light is reflected by a mirror. In this latter case you do not see the mirror but the light source or the illuminated object from which the light falls on the mirror. It means that if all non-luminous objects had perfectly smooth surfaces we would not be able to see them, for by looking at them we would only see the light sources reflected at the smooth surfaces.

**How Light Travels.** The flame of a candle gives off light all around it. From each part of the flame light starts in straight lines and goes out in all directions. Any one of these straight lines along which light travels is called a ray of light.

Arrange two equal strips of cardboard over each other and pierce a hole through their centres. Support the two strips in an upright position with the help of books. Place one in front of the other. Put a lighted candle before one of them so that the flame is in line with the hole in the second strip of cardboard. The flame will be visible when it is in the same straight line as the two holes of the cardboard. If one of the strips be slightly moved the flame will not be seen. This simple experiment proves that light travels in straight lines.



*Light travels in straight lines.*

When light strikes a surface it is reflected off that surface or passes right through it. A material which allows us to see through it is said to be transparent. Many useful articles are made of glass because it is transparent. There are yet other kinds of materials that allow some light to pass through, but not enough to see clearly through them. These materials are called translucent. When rays of light fall on frosted glass they become twisted and broken and mixed. For this reason we see some of the light which passes through but not enough to make out what is on the other side. Anything that completely blocks the path of light is called opaque.

**Shadows.** When an opaque body is placed before a source of light the region on the other side of the body will be in darkness because light cannot pass through it. This region of darkness is called a shadow. The formation of a shadow is further proof that light travels in straight lines. The type of shadow produced depends on the relative sizes of the source of light and of the opaque body before it.

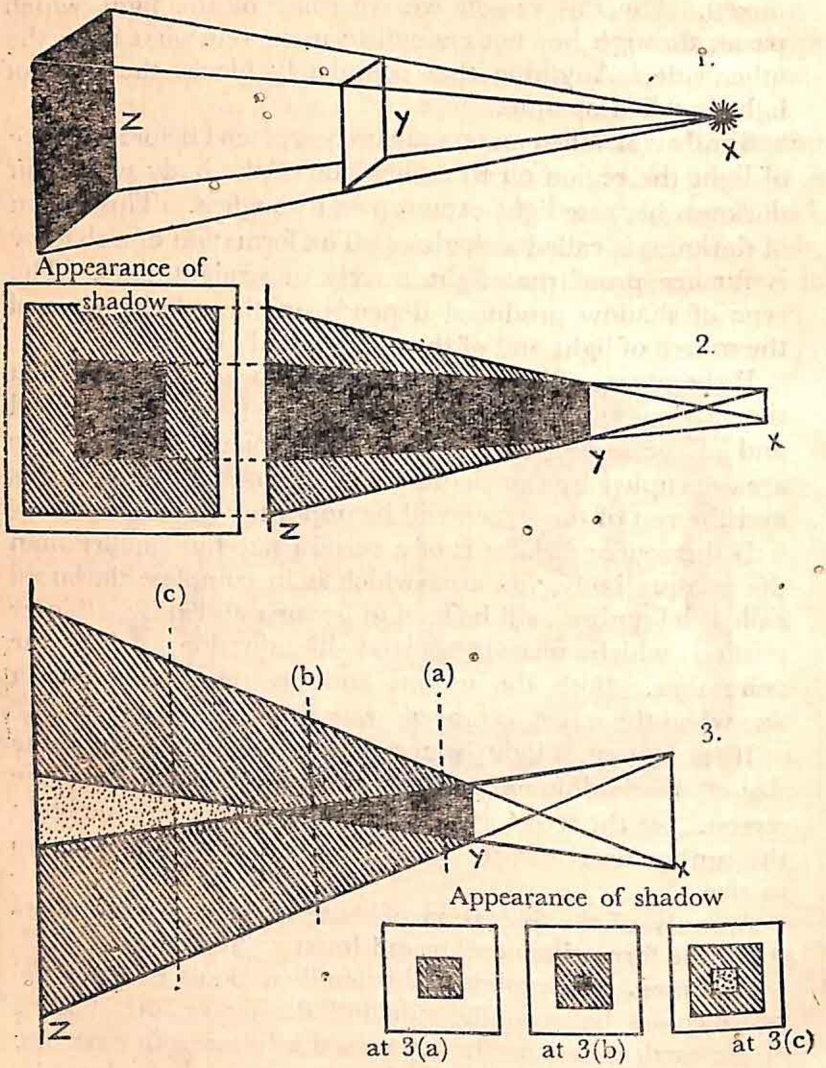
If the source of light is a single point it will be found that the shadow as formed on a screen will be sharply defined and of the same shape as that of the opaque body. The area occupied by the shadow will be in complete darkness and the rest of the screen will be uniformly illuminated.

If the source of light is of a certain size but smaller than the opaque body, the area which is in complete darkness, called the umbra, will be seen to be surrounded by a fainter portion which receives partial illumination, called the penumbra. Both the umbra and penumbra increase in size when the screen is moved away from the opaque body.

If the source of light is larger than the opaque body, the size of the shadow obtained depends on the position of the screen. As the screen is moved away from the opaque body the umbra decreases in size while the penumbra increases in size.

A study of the formation of shadows helps us to understand the formation of solar and lunar eclipses.

**Eclipses.** As explained in detail in Book I, when the earth comes between the sun and the moon, the shadow of the earth is cast on the moon and a lunar eclipse occurs. A total lunar eclipse occurs when the moon passes into the umbra region of the shadow; while in the penumbra region of the shadow the eclipse is partial.

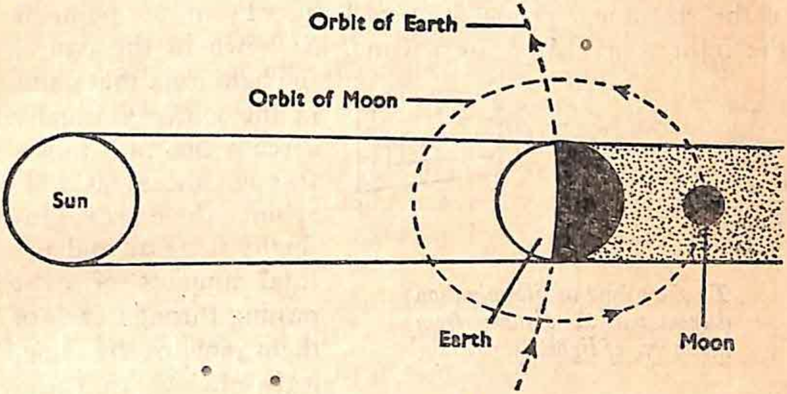


*Shadows.*

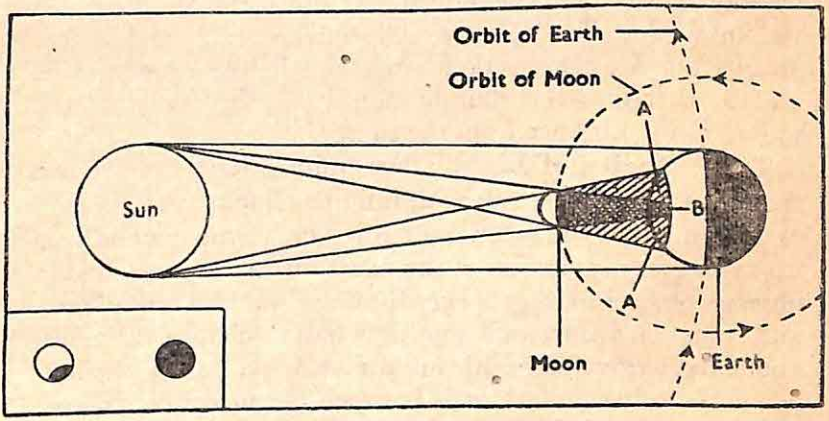
*x, source of light; y, object; z, screen.*

*Full black shading denotes umbra, lined shading and dotted shading denote penumbra.*

When the moon comes between the sun and the earth the umbral cone of the moon is very narrow and people in this area can observe a total solar eclipse. People in the penumbra region, however, will observe a partial solar eclipse.

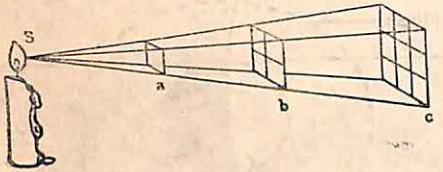


*An eclipse of the Moon.*



*An eclipse of the Sun.*
*A, Penumbra region—view point area of partial eclipse.*
*B, Umbra region—view point area of total eclipse.*
*Inset : How the sun appears during a partial eclipse (left), and a total eclipse (right).*

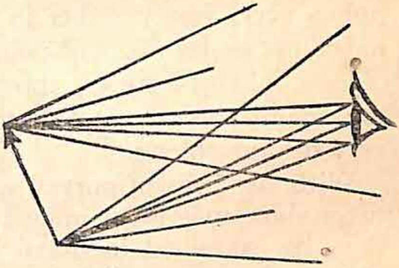
**Illumination Decreases with Distance from the Source.** You know by experience that the further away you are from a lamp the less bright appears the sheet of paper you hold up to the light from a lamp. This is a direct consequence of the rectilinear propagation of light. From one point in the light source *S*, draw a cone, as shown in the figure, the light from that point in the source gradually spreads out and passes through the areas *a*, *b*, *c*; since these areas gradually increase and the total amount of light passing through each of them remains the same, it is obvious that the illumination, that is, the light per unit area, decreases as we move away from the light source. In fact from geometry we know that if *a*, *b*, *c* are respectively 1, 2, and 3 feet away from the source, their areas are in the ratio of 1, 4 and 9, therefore the illumination varies inversely as the square of the distance from the source.



*To show how the illumination decreases as the distance from the source of light (S) increases.*

**The Velocity of Light.** For quite a long time it was thought that light travels with infinite velocity, that as soon as the lamp is lit you see its light however far you may be from it. When the invention of the telescope made it possible to observe objects at very large distances, such as the planets and stars, scientists found that they had to change their idea about light travelling with infinite velocity. In particular, when observing the intervals between the successive eclipses of the moon of Jupiter, the Danish astronomer Romer discovered some irregularities in the timings. These could only be satisfactorily accounted for by assuming that light took some time to come from Jupiter to the Earth. Romer's measurements and those of the scientists after him, who made more precise measurements, have clearly shown that light travels in empty space with a speed of 300,000 Km. or 186,000 miles per second. This means that the light from the sun takes about $8\frac{1}{2}$ minutes to reach us. It was further found that light travels more slowly when traversing material bodies, the velocity decreasing with increasing density. Thus in air the velocity of light is practically the same as that in vacuo, in water it is $\frac{3}{4}$ that in vacuo, in ordinary glass it is $\frac{2}{3}$ that in vacuo, in diamond $\frac{5}{12}$ that in vacuo. Whereas, the velocity of light in vacuo is the same for all colours, when the light traverses material bodies its velocity varies with the colour of light, increasing from violet through green to red.

**Vision and Aids to Vision.** How do we actually see objects by the light rays sent out by them? From each point of the object, rays of light spread out in all directions, and narrow bundles of these rays enter the pupil of the eye. Then the eye itself acting as a combination of lenses brings each of these bundles to meet at a point on the back of the eye, and so reproduces there a miniature image of the object. The way in which the eye accomplishes this image formation is indeed marvellous, yet there are quite a number of cases in which the eye can be aided by man-made inventions to improve its vision. This is naturally the case when the eye is defective, but even when the eye functions normally there are many cases when the eye, left to itself, would not be able to see objects and especially to see them distinctly and in great detail, in



*From each point of an object rays of light spread out in all directions.*

which cases optical instruments are used to improve its vision.

We have said that light travels in straight lines. Therefore, unless the object is in front of us, no rays of light coming from the object will be able to reach us, unless we have a way of altering the directions of the rays of light, and that is the function of mirrors and prisms.

The further the object is from the eye, the smaller is the amount of light from each point of the object entering the pupil of the eye, and therefore the fainter the image produced at the back of the eye, until finally, for very distant objects, the image is too faint to make an impression on the eye. This can be remedied if the light from larger bundles of rays coming from each point of the object can be brought closer together and made to enter the pupil of the eye; this of course will mean a brighter image. This can be realised by the use of curved mirrors and lenses, gathering all the light falling over the whole area of a mirror or a lens and focussing it on the pupil of the eye or at whatever place we want a bright image.

If an object is very small it is very difficult for the unaided eye to see clearly the various details of the objects, because points very close together in the object when seen by the naked eye appear like one point or a small blur. Even large objects, when far away, appear very small and once again the unaided eye is not able to see the detailed structure of very distant objects.

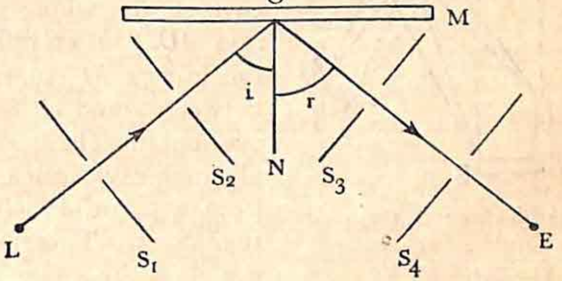
With the help of curved mirrors or lenses it is possible to produce magnified images of distant objects which can then be examined in detail by the eye either directly or after having recorded them on a photographic plate.

In order to understand the special functions and properties of flat and curved mirrors, and of lenses, it is necessary first to study some general laws governing the propagation of light when reflected by mirrors or when passing through transparent substances like glass.

**Reflection of Light by Plane Mirrors.** We have already mentioned that smooth, mirror-like surfaces reflect light in a special manner, which differs from the way light is reflected from more or less rough surfaces. To distinguish between the two we refer to the first as reflection and to the other as diffusion of light.

We consider here the case of reflection of light by smooth surfaces, like mirrors. When you stand straight in front of a flat mirror you see your own figure in the mirror which is of the same size as yourself. If you stand on one side of the mirror you no longer see yourself in the mirror, but you see some objects that are some distance away from you on the other side of the mirror. To make this more precise, arrange the following simple experiment.

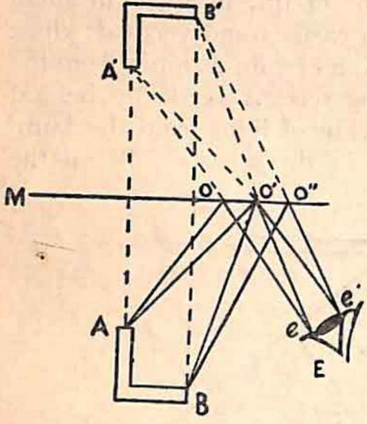
Fix on a table a plane mirror in the vertical position, take four strips of cardboard or of tin, fit them in small blocks of wood so that they can easily stand vertical: these we call screens. Place a lamp at a certain distance from the mirror, and arrange two of the screens vertically behind each other so that a narrow beam of light from the lamp passing through the two holes in the screens falls on the



*Reflection of light by a plane mirror.*
*E, eye; L, lamp; M, mirror; NO, normal; O, a point on the mirror;* $S_1$, $S_2$, $S_3$, *and* $S_4$, *screens; i, angle of incidence; r, angle of reflection.*

mirror at a given angle. Then arrange the other two screens at a distance behind each other in such a way that you see through the holes in the screens the narrow beam of light reflected at the mirror. By drawing lines on the table just below the holes in the screens, you can easily verify that the ray of light from the lamp incident on the mirror at *O* is reflected along *OE* in such a way that the incident ray *LO* and the corresponding reflected ray *OE* are equally inclined to the mirror but on opposite sides. This is usually stated as follows: the incident and reflected rays make equal angles with the normal at the point of reflection (*ON* is the normal).

We will now study how we actually see objects by reflection at a plane mirror. Consider two points *A* and *B* of a given object sending out light rays in all directions. One ray *AO* after reflection at the mirror *M* moves along *Oe* where it enters the pupil of the eye, another ray *AO′* is similarly reflected along *O′e′* and also enters the eye. In fact, the whole bundle of rays *AOO′* after reflection at the mirror *M* enters the eye between *e* and *e′*, and to the eye looking along *eo* and *e′o′* all these rays appear to come from a point *A′* where these rays meet. Therefore to the eye *A′* is the image of *A*. We may apply the same reasoning to the narrow bundle of rays from *B* reflected at the mirror between *O′* and *O″*, all these

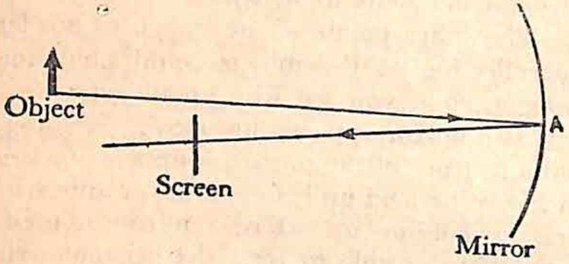


*The upside-down image of the letter L in the mirror is caused by the reflection of light rays from the mirror (M) to the eye (E) in the pattern of the unbroken lines.*

rays entering the eye appear to come from the point $B'$ which to the eye is the image of $B$ as seen by reflection in the mirror. It is easy to see that the points $A'$ and $B'$ are as far behind the mirror as the points $A$ and $B$ are in front of it. Since the bundles of rays after reflection do not actually meet at the point, but only appear to meet, to the eye looking along these rays, we say that the image is virtual. The other points of the image of the letter $L$ as seen by reflection at the mirror could be found in the same manner, and you see why an object when seen by reflection at a mirror appears 'inverted'. Holding up your right hand in front of the mirror, it appears to you as your left hand; writing held up before a mirror appears inverted, therefore, by holding up before a mirror a used blotting paper you may be able to read the original writing that has been blotted with it.

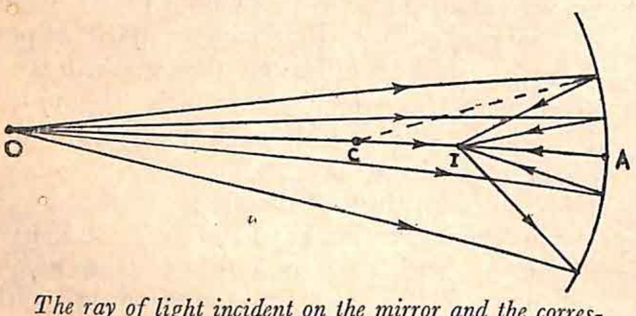
**Spherical Mirrors.** A spherical mirror is a part of a smooth spherical surface. If the smooth reflecting surface is on the hollow side it is called a concave mirror; if reflection takes place at the bulging side it is called a convex mirror.

If you hold a concave mirror in the sunlight, you will find that all the sunrays after reflection converge to a very small area, and if you hold a piece of paper there it will catch fire very soon. This clearly demonstrates the focussing power of a concave mirror. Replacing the piece of paper by a white screen or a sheet of frosted glass you will see a very small image of the sun which is extremely bright; it means that small bundles of rays from each point of the sun after reflection at the mirror have been made to converge to a set of points reconstituting the shape of the sun, that is what we call forming an image of the sun. It is a reduced image of the sun, and it is very bright because all the rays from each point of the sun falling on the whole surface of the mirror have been brought to a point in the image. You may repeat the same experiment by placing a lighted candle or a lighted electric lamp at a given distance from the mirror and observing its image on a small screen held at the right place, where the rays from the object after reflection at the mirror are focussed. By varying the distance of the object from the mirror, you will find that the distance of the image is measured from the mirror also gradually changes and so does the size of the image. This time it is a real image that is formed by the mirror, an image that could be photographed.



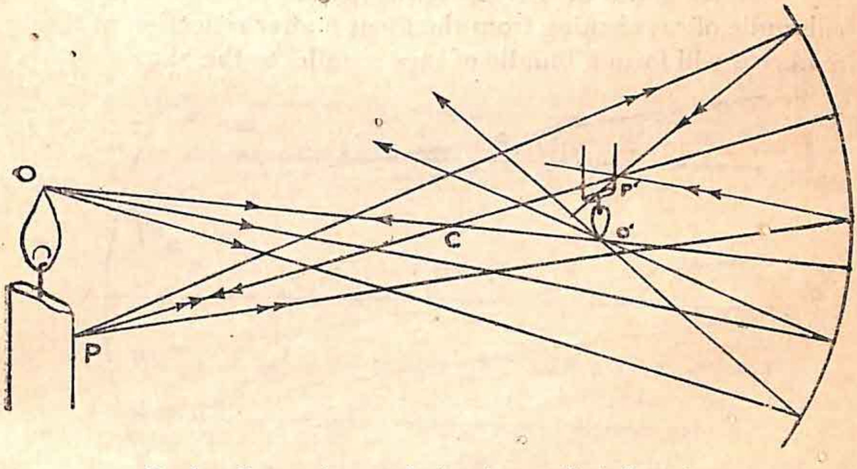
*To show the position of the screen when studying the image of an object as formed by a concave mirror.*

**How a Concave Mirror Forms an Image.** It is still the application of the simple rule that the ray of light incident on



*The ray of light incident on the mirror and the corresponding reflected ray make equal angles with the normal at the point of reflection.*

the mirror and the corresponding reflected ray make equal angles with the normal at the point of reflection. Draw a line through *A*, the centre of the mirror, and perpendicular to it; this line passes through *C*, the centre of the sphere of which the mirror is a portion. This point is called the centre of curvature of the mirror. The line *AC* is called the axis of the mirror. Consider a small light source at *O* on the axis of the mirror and light rays diverging from *O*. One ray along *AC* is incident at right angles on the mirror at *A* and is reflected back along the same direction, other rays are incident at other points making various angles with the normal at the points of incidence. These angles increase as the points are further away from *A*; therefore the reflected rays are also turned away further from the incident ray and the result is that all the rays from one point *O*

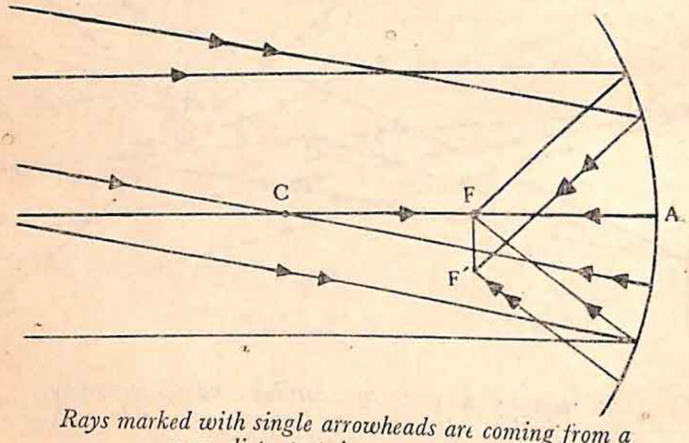


*To show how an image of a burning candle is formed by the reflection at the mirror of bundles of rays from each point of the candle.*
*C, centre of mirror; O′P′, image of O P formed by concave mirror.*

after reflection meet practically at another point $I$ on the axis. $I$ is the image of $O$; this also holds in the case of points not on the axis.

**Principal Focus—Focal Length.** When we consider light from an object at a considerable distance from the mirror, then a small bundle of practically parallel rays of light from each point of the object reaches the mirror; in this case all the bundles of rays are focussed at points forming the image in a plane which is called the focal plane of the mirror and which is situated midway between the centre of curvature of the mirror $C$ and the mirror itself. $F$, the point of intersection of this plane with the axis, is called the principal focus of the mirror and the distance $AF=f$ is called the focal length, naturally $f=\frac{r}{2}$ where $r$ is the radius of curvature of the mirror.

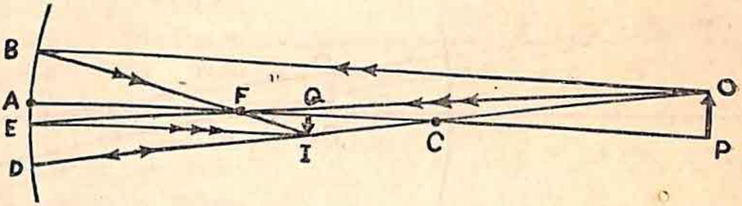
Reversing the direction of the rays it is obvious that a bundle of rays issuing from the focus $F$ after reflection at the mirror will form a bundle of rays parallel to the axis.



*Rays marked with single arrowheads are coming from a very distant point on the axis.*
*Rays marked with double arrowheads are coming from a point which is not on the axis.*

We have just seen that a ray of light which travels parallel to the axis of the mirror, after reflection at the mirror, passes through its focus. We know also that a ray passing through the centre of curvature of the mirror will be incident on the mirror at right angles and therefore be reflected back along the same direction. On the other hand, we assume that all rays issuing from a point after reflection intersect at another point which is the image; therefore, if we choose any two rays from a point and find the place where they intersect after reflection we get the image of the point. Of the two rays chosen for this, one moves parallel to the axis of the mirror and the other passes through the centre of curvature or at times also we may consider a ray passing through the focus, because such a ray after reflection at the mirror becomes parallel to the axis of the mirror.

Consider the point *O* and two or three rays issuing from it. *OB*, parallel to the axis *CA*, after reflection, passes through

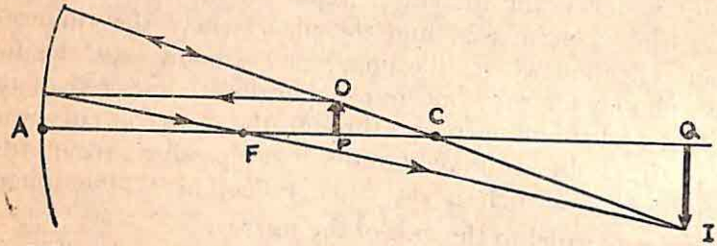


*When the object is beyond the centre of curvature (C) the image is between C and the Focus (F).*

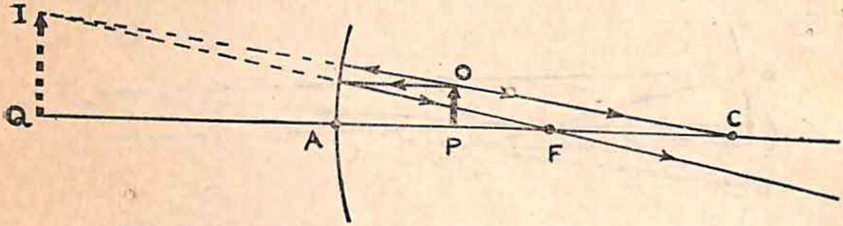
the focus *F*, and *OCD* which is reflected back along the same direction. *I*, the point of intersection of the reflected rays, is the image of *O*. Since *PO* is normal to the axis *CA*, we assume that its image is also normal to the axis, therefore a perpendicular through *I* on *CA* gives *QI* as the image of *PO*. It is seen that the image is inverted and diminished.

Instead of one of the above two rays we might have taken the ray *OF* through the focus which after reflection at *E* becomes parallel to the axis and then intersects any of the other two rays at *I*. This graphical method of determining the position, magnitude and nature of the images formed by a concave mirror can be applied to various cases when the object is at different distances from the mirror.

Two interesting cases are those when the object is placed between the centre of curvature and the focus, or between



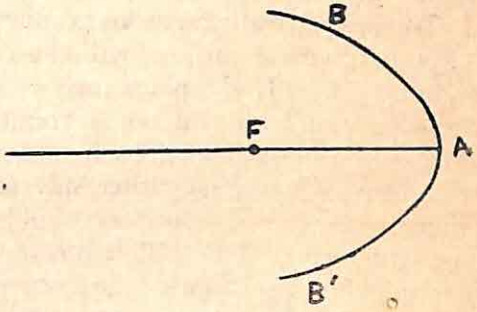
*When the object is between the centre of curvature (C) and the Focus (F), the image is beyond C.*



*When the object is between the focus (F) and the centre of the mirror (A) the image is virtual.*

the focus and the mirror. In the first case we get an enlarged, inverted and real image. In the other, the rays after reflection are diverging, and to the eye looking along them, they appear to meet at a point *I* behind the mirror. Therefore we get a virtual, erect and enlarged image when the object is very close to the mirror, closer than the focal length, such is the case of a curved shaving mirror held close to the face.

When we use fairly large mirrors, it is found that their focussing properties are not perfect, that means that a rather wide bundle of rays after reflection at various points of the large mirror do not all meet at a point, but different rays intersect at different points forming a little blur, hence the image of an object formed in this way will also be a little blurred. In the case of very distant objects, especially the planets, stars, nebulae and so on, it is essential to use large mirrors if we want bright images, since the brightness depends on the width of the mirror, which is referred to as its 'aperture', but then the image is no more distinct. It was found that the latter defect can be eliminated by using parabolic mirrors instead of spherical mirrors. A parabolic surface is obtained by rotating a parabola about its axis. When using such a type of reflecting surface the whole bundle of parallel rays from a distant point situated on or close to the axis of the parabolic surface when reflected at this mirror is focussed exactly at one point. This holds even in the case of large bundles of rays which cover mirrors of apertures as large as 100 or 200 inches. We shall see applications of this in the case of giant reflecting telescopes.



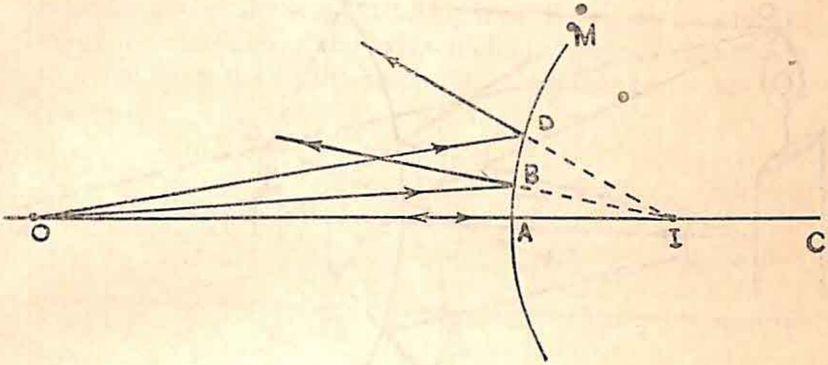
*A parabolic mirror.*
*BAB', parabola; F, Focus of parabola. By rotating the curve BAB' about its axis AF we generate a parabolic surface.*

The light gathering power of such parabolic mirrors has also been clearly demonstrated by using large mirrors of that type to focus the light of the sun, the heat produced at the focus is so intense that it melts even the most refractory metals, temperatures of over 3,000°C. have been obtained in this way.

Reversing the above process, we place a powerful light source at the focus of such a mirror, then the rays from this source after reflection will be concentrated into a narrow beam parallel to the axis of the mirror. Since the light does not spread out sideways, the intensity of the luminous beam will remain great even at large distances. This is the arrangement adopted in the case of floodlights to illuminate buildings or monuments and also in the case of searchlights which send high up into the sky beams of light, which like giant luminous fingers, can be made to sweep the whole sky by gently rocking the mirror from one side to the other.

**Convex Mirrors.** A convex spherical mirror is a part of a smooth spherical surface with the reflecting surface on the bulging side. If you place such a mirror right in front and close to you, you will see a greatly diminished image of yourself. If you hold the mirror at a certain distance from you, you will see, on either side of your own image, the images of quite a number of objects on either side of you and behind you. This means that your field of view behind you, has been made very wide by the use of this mirror. Holding the mirror to one side you see the images of objects that are behind you further away on that side, but if you try to receive these images on a screen held at the place where your eye saw them at first you will not succeed, which indicates that the images you saw were virtual images, i.e. images formed by your eye looking along bundles of rays converging to points at the back of the mirror.

The working of a convex mirror can be explained as in the case of concave mirrors by applying to this case the fundamental law that the incident and corresponding reflected rays make equal angles with the normal to the mirror at the point of incidence. Consider a bundle of rays issuing from a point $O$ on the axis $AC$ of the convex mirror. The

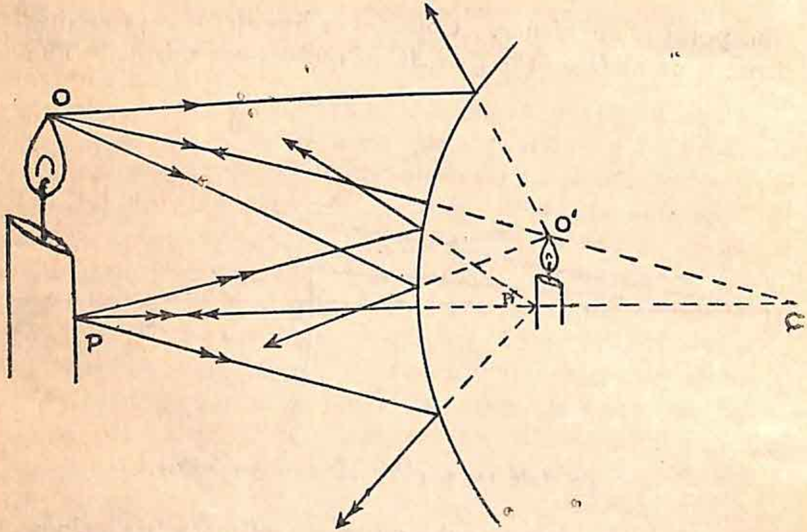


*To show the working of a convex mirror.*

ray $OA$ being normal to the mirror is reflected back along the same direction; the rays $OB$, $OD$ etc. make gradually greater angles with the normals at $B$, $D$, etc. and therefore are reflected back along directions gradually diverging further from the incident rays, so that only by producing these reflected rays beyond the mirror will they meet somewhere at a point, $I$, which is the virtual image of the object point $O$.

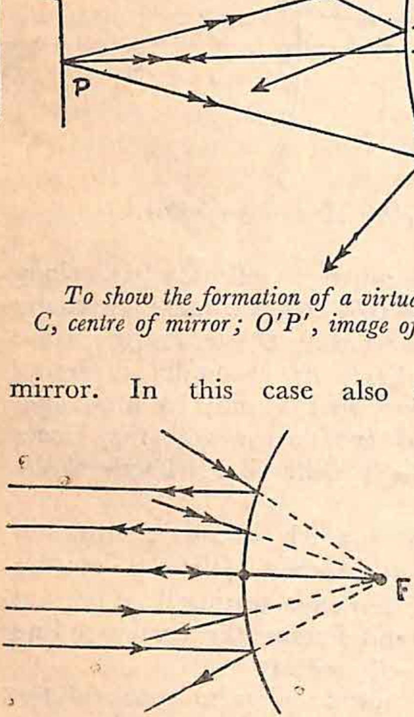
The formation of a virtual image by a convex mirror of an object placed in front of it, is shown in the top diagram on page 80, by considering a few rays starting from each of a few points in the object and finding the corresponding points of intersection of the reflected rays.

In the case of a convex mirror we also speak of the principal focus which is the place on the axis where the images of very distant objects are focussed. The distance of the principal focus from the mirror, called focal length, is also half the radius of curvature of the mirror. Therefore the focus is obviously at the back of the



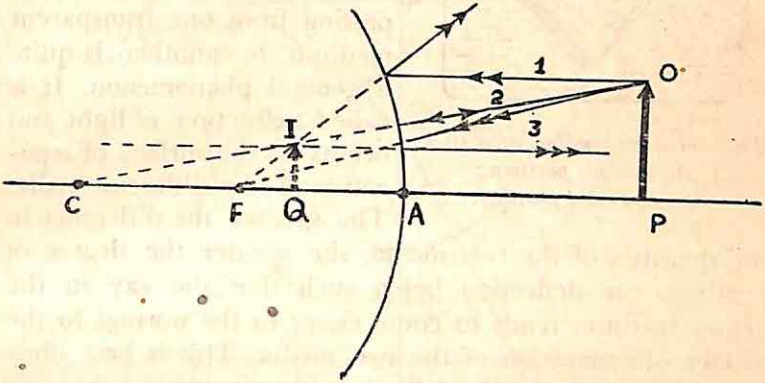
*To show the formation of a virtual image by a convex mirror.*
*C, centre of mirror; O'P', image of OP formed by convex mirror.*

mirror. In this case also it means that a beam or rays parallel to the axis after reflection is changed into a bundle of divergent rays appearing to come from the focus; and vice versa, a bundle of rays converging on the focus, after reflection at the mirror will be transformed into a bundle of rays parallel to the axis.



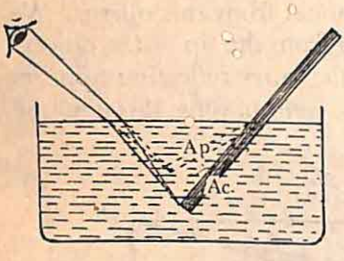
*Light rays parallel to the axis of a convex mirror, after reflection, are changed into a bundle of divergent rays appearing to come from the focus and vice versa.*

This again provides us with an easy graphical method to determine the position and magnitude of the image formed by reflection at a convex mirror by the rays from an object placed at various distances from the mirror. We consider two or three rays starting from the tip of the object: firstly, one parallel to the axis which after reflection appears to come from the focus; secondly, one passing through the centre of curvature of the mirror which will be reflected back along the same direction and thirdly, one going in the direction of the focus which after reflection will be parallel to the axis. The diagram gives one practical illustration of this method. As seen from its construction, the image *QI* is virtual, erect and diminished. This is the case for every position of the object. As the object moves further away from the mirror, the position of the image moves closer to the focus *F*.



*To show the virtual image formed by a convex mirror.*

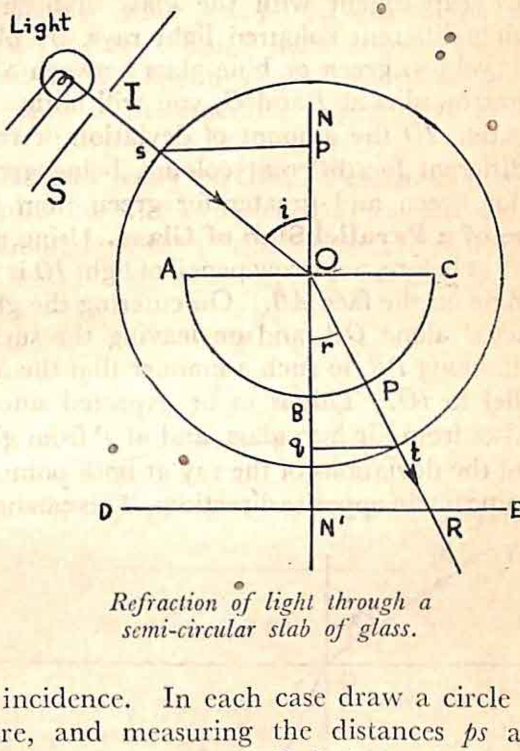
**Refraction of Light.** When you look at a stick partly immersed in water it appears to be bent at the surface of the water. The stick, of course, is neither bent nor broken, but it is the rays of light coming from the immersed portion of the stick which at the surface of the water are bent and therefore when you look along these rays you see the immersed portion of the stick as if it were raised in the water and therefore it no longer appears to be in a line with the portion of the stick outside the water.



*The apparent bending of a stick.*
*Ac., actual position;*
*Ap., apparent position.*

This phenomenon of the bending of a ray of light when passing from one transparent medium to another is quite a general phenomenon. It is called refraction of light and occurs at the surface of separation of two different media. The greater the difference in the densities of the two media, the greater the degree of bending, the deflection being such that the ray in the denser medium tends to come closer to the normal to the surface of separation of the two media. This is best illustrated by arranging the following experiment.

Take a semi-circular slab of glass *ABC*, and place it horizontally on a rather broad block of wood with a sheet of white paper between the two . Cover the side *AC* with opaque paper leaving a narrow vertical slit *O*, at the centre of the semi-circle. Place a light source behind the screen *S* with another narrow vertical slit *I*, in line with the slit at *O* so that a ray of light falls at a slant along *IO*, on the flat glass surface. There it will be refracted along the direction *OP* and, being normal to the curved glass surface at *P*, it will emerge along *OPR* without further deviation. The emerging ray may be received on a small screen (preferably a transparent one) placed along the line *DE*. Trace the outline *ABC* on the paper underneath and also trace the incident ray *IO*, the refracted ray *OR* and the normal *NON'* to the refracting surface *AC* at *O*. Thus the angle of incidence $i$ and of refraction $r$ can be measured and it will be seen that *i* is always greater than *r*. The experiment is to be repeated for various values of the

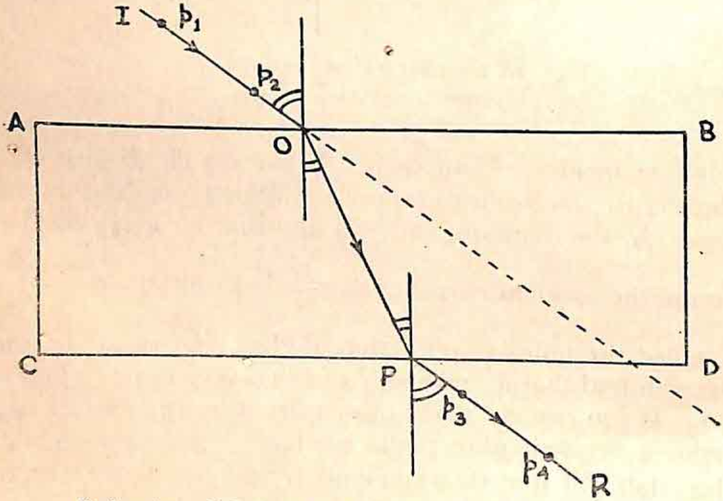


*Refraction of light through a semi-circular slab of glass.*

angle of incidence. In each case draw a circle with *O* as the centre, and measuring the distances *ps* and *qt*, as shown in the diagram, you will find that for every inclination of the incident ray, the ratio $\frac{ps}{qt}$ is a constant, $n = \frac{ps}{qt}$ is called the index of refraction of glass relative to air, and you will find that for ordinary glass *n* is very nearly equal to 1·5. If you can get a few thin strips of transparent plastic, make a semi-circular tank, similar to the semi-circular glass slab, fill it with water and repeat the above experiment. In this case you will be studying the refraction of light passing from air to water and you will find that the value for *n* for water is very nearly 1·33.

The above experiment with the glass slab should be repeated using different coloured light rays, by placing a sheet of red, yellow, green or blue glass between *S* and *O*, and using narrow slits at *I* and *O*, you will notice that for a fixed direction *IO* the amount of deviation or refraction is slightly different for different colours, being greater for blue than for green and greater for green than for red.

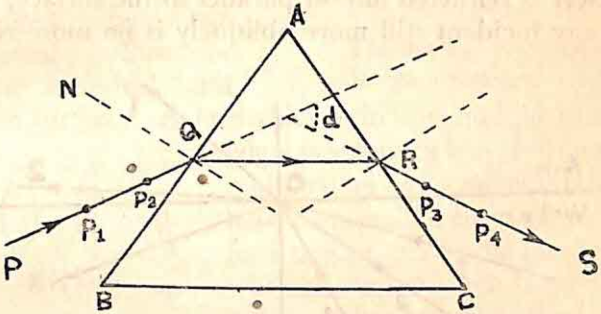
**The Case of a Parallel Slab of Glass.** Using the same arrangement as before, a narrow pencil of light *IO* is made to fall at an angle on the face *AB*. On entering the glass, this ray is refracted along *OP*, and on leaving the surface *CD* it is refracted along *PR*, in such a manner that the direction *PR* is parallel to *IO*. This is to be expected since, at *O*, the light passes from air into glass, and at *P* from glass into air, therefore the deviations of the ray at both points should not be the same but in opposite directions. This can be verified



*Refraction of light through a parallel slab of glass.*

by fixing two pins $p_1$, $p_2$ along *IO*, and, looking through the glass slab until the two pins appear in a line. Along this line fix two other pins $p_3$, $p_4$. Draw the lines *IO* and *PR* and draw lines through the two pairs of pins and thus verify that the two lines are parallel and that there is merely a lateral shift of the emergent ray relative to the incident ray.

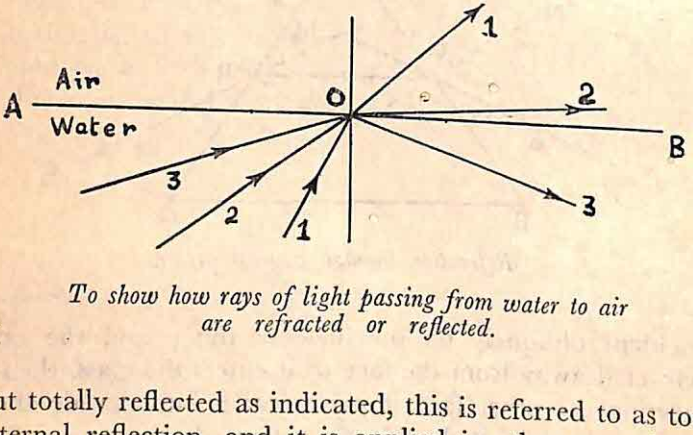
**Refraction through a Glass Prism.** A prism is a transparent substance with two plane surfaces inclined at an angle called the angle of the prism. If a narrow beam of light is incident obliquely on one face of the prism, the ray is refracted away from the face as it enters the glass, then on meeting the other face it passes again into the air and is once again refracted, this time towards the face. Place the prism on a soft board with a sheet of paper between the board and the prism and fix two pins along the incident ray *PQ*. Look through the face *AC* until along the direction *RS* you see the first two pins in a line, then fix two pins along the line *RS*. Draw on the paper the outline of the prism *ABC*. Next draw the lines *PQ* and *RS* and join *QR* which shows the path followed by the ray on passing through the prism. By prolonging *PQ* the angle *d* it makes



*Refraction through a glass prism.*

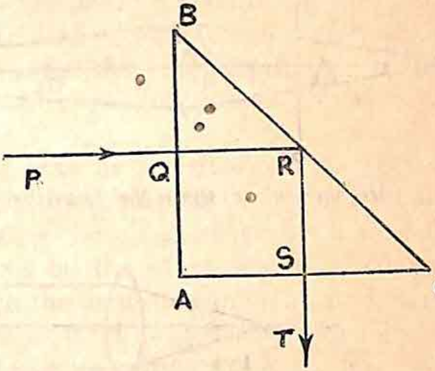
with the prolongation of *RS* gives the total deviation of the ray when passing through the prism. On varying the angle of the incident ray with the normal *NQ* to the face *AB*, it is found that the total deviation varies. The angle of deviation also depends on the angle of the prism *A* and on the nature of the material of the prism—the denser the material, the greater the deviation.

**Total Internal Reflection.** Consider the surface *AOB* with water below and air above. A ray incident at *O* is refracted into the air as indicated; another ray, incident more obliquely is refracted almost parallel to the surface, while a third ray incident still more obliquely is no more refracted but totally reflected as indicated, this is referred to as total internal reflection, and it is applied in the case of rectangular prisms used for reflection purposes instead of ordinary mirrors.



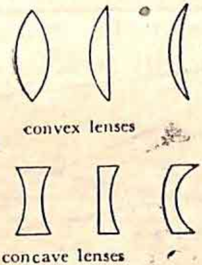
*To show how rays of light passing from water to air are refracted or reflected.*

Consider a rectangular prism *ABC*. A ray *PQ* incident normally on the face *AB* passes into the prism undeviated along *QR*. The angle made by *QR* with the normal to the surface *BC* is such that the refracted ray would make an angle with the normal greater than a right angle, therefore, the ray *QR* is totally reflected along *RS* and then emerges through $CA$ undeviated along $ST$. On account of this, when you look into such a prism along a direction $SR$ you see the objects situated along $QP$.



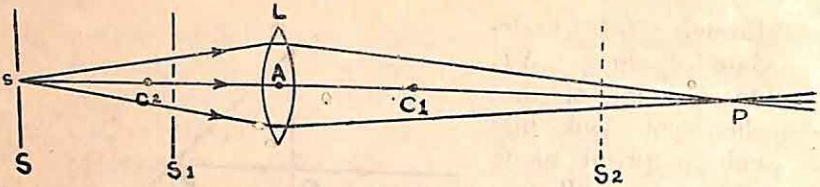
*The course of a ray of light through a rectangular prism.*

**Lenses.** A lens is a transparent substance usually bounded by two spherical surfaces or by a spherical and a flat surface. A lens thicker in the middle than at the edges is a convex lens; if thinner in the middle than at the edges it is a concave lens. Lenses, like curved mirrors, have focussing properties i.e.bundles of rays when passing through them are deviated in such a way that they meet at a poin to rappear to proceed from apoint.

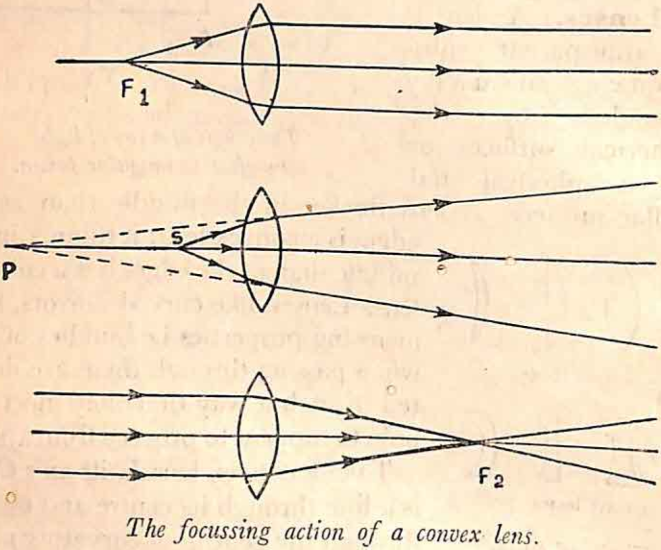


*Kinds of lenses.*

Take a convex lens $L$, its axis $C_2AC_1$ is a line through its centre and passing through the centres of curvature of the two curved surfaces $C_1$ and $C_2$. Put a bright lamp behind the screen $S$ in which there is a small hole $s$ on the axis $C_2AC_1$. Rays diverging from $s$ after passing through the lens will converge to a point $p$ on the axis. If the hole $s$ is moved towards the lens the point $p$ will move further away from the lens, until $s$ is in a position $F_1$ for which the rays after passing through the lens come out parallel to the axis, therefore meeting at infinity. This point $F_1$ is of course one principal focus of the lens. If the hole $s$ is moved



*Arrangement to study the focussing property of a convex lens.*



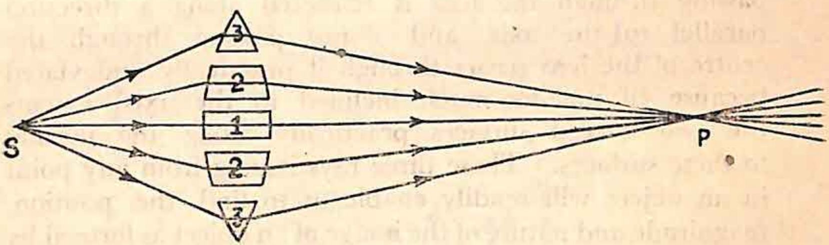
*The focussing action of a convex lens.*

still closer to the lens, the rays after passing through the lens will diverge and if produced backwards will meet at a point $p$ on the axis. If a narrow beam of sunlight is made to fall on the lens along the axis all the rays will, after refraction, converge to a bright point $F_2$ on the axis, and of course this is the other principal focus of the lens.

The above experiments will be more striking if a screen $S_1$ is placed between $S$ and $L$, with a few holes in it, and another screen $S_2$, preferably of frosted glass, is held on the other side of the lens and gradually moved along the axis, so that the paths of the refracted rays can easily be followed. If some smoke is blown around the lens, then the paths of the rays before and after refraction will be clearly seen.

The above experiments may be repeated, replacing the screen *S* and the small hole, by a burning candle or a small electric bulb, and observing the clear image on a frosted glass moved along the axis on the other side. Of course when the object is between the focus and the lens, no image can be seen on the screen as the image is a virtual image. To observe the image at the focus, a distant object is focussed by means of the lens on the screen.

**Explanation of the Focussing Action of a Lens.** We may consider the convex lens as made up of a series of small truncated prisms for which the angle of deviation gradually increases. The rays diverging from a point *s* fall on the prisms, 1,2,3, etc., the prisms having gradually decreasing angles

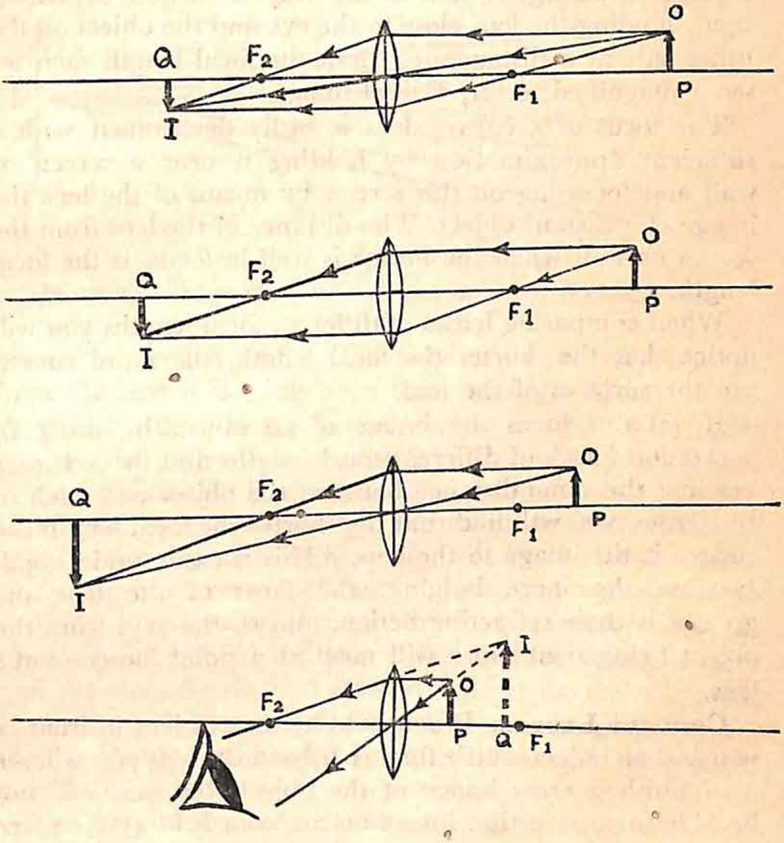


*A convex lens may be considered to be made up of a series of small truncated prisms of which the angle of deviation gradually decreases.*

and the rays being incident on them in a gradually more oblique way. The rays after refraction through them are also gradually bent through a larger angle, and so are made to meet at *p*. If *s* is between the focus and the lens, it means that all the rays after passing through the various prisms are bent by various amounts, but on emerging they are still diverging and hence appear to come from a point on the same side of the lens as the light source *s*. The same reasoning applies to the case of a bundle of rays issuing from a point not on the axis, but in this case all the rays after refraction will meet at a point, or appear to come from a point, not on the axis.

The light-gathering power of a lens is also clearly shown in the above explanation. Since all the rays from a point falling over the whole surface of the lens are made to meet at a point, a convex lens can be used as a 'burning glass'. When such a lens is held in the rays of the sun, a minute image of the sun will be produced at the second principal focus of the lens and will rapidly set on fire a piece of paper held at that place.

We have already shown that a ray parallel to the axis of the lens, after refraction through the lens, passes through its second focus, a ray passing through its first focus and then passing through the lens is refracted along a direction parallel to the axis, and a ray passing through the centre of the lens passes through it practically undeviated because (if not too much inclined to the axis) it cuts the two curved surfaces practically along the normal to these surfaces. These three rays issuing from any point in an object will readily enable us to find the position, magnitude and nature of the image of an object as formed by a convex lens. The graphical method used is exactly similar to the one used in the case of a concave mirror. We illustrate the method by a few practical cases: the three rays 1, 2, 3 are those referred to above; any two of these will suffice to indicate the position of $I$ the image of the object point $O$. Then by dropping a normal through $I$ on the axis we have $QI$ the image of $PO$. For objects at distances from the lens equal or greater than the focal length, the image is real and inverted. A special case is the one where the object is at a distance twice the focal length from the lens, then it is clearly seen that the inverted image has the same size as the object. Such an arrangement can be used to invert the appearance of an object, without altering its size. It



*To show the formation of images by a convex lens.*

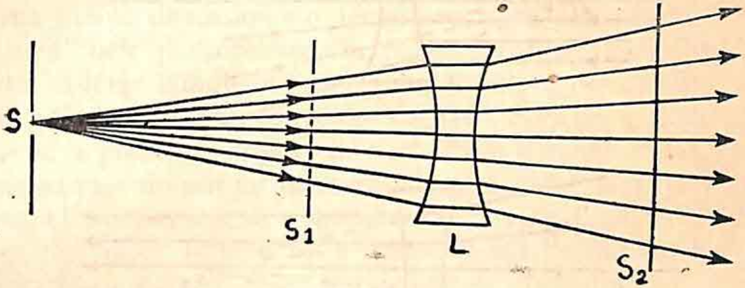
is also clear that if the object is at a distance from the lens less than twice the focal length and more than the focal length, a real and enlarged image is produced, and the closer the object is to the focus the larger is the image. In case the object is at the focus then of course the image would be formed at infinity. If the object is between the focus and the lens the construction shows that the image is virtual, erect and enlarged: this is the way a magnifying lens is used: holding the lens close to the eye and the object on the other side at a distance less than the focal length then we see a magnified, erect, virtual image.

The focus of a convex lens is easily determined with a sufficient approximation by holding it near a screen or wall and focussing on this screen by means of the lens the image of a distant object. The distance of the lens from the screen or wall when the image is well in focus, is the focal length.

When comparing lenses of different focal lengths you will notice that the shorter the focal length, the more curved are the surfaces of the lens.

If you now focus the image of an object by using in succession lenses of different focal lengths and in each case keeping the same distance between the object and each of the lenses, you will find that the shorter the focal length the nearer is the image to the lens. This is easily understood, because the more bulging, the faces of the lens the greater is their refracting action, and so the rays from the object being bent more will meet at a point closer to the lens.

**Concave Lenses.** If you hold a concave lens in front of you and an object a little further behind the lens you will see a diminished erect image of the object, but you will not be able to receive that image on a screen held at the place where your eye saw the image. It means that you saw a virtual image and that the bundles of rays from each point of the object after passing through the lens were diverging more and therefore to the eye they appeared to come from points closer to the lens than the object itself. This may be clearly demonstrated by the following arrangement: a light source $S$ behind a screen with a narrow hole, the concave lens $L$, a screen $S_1$ with a number of holes in it

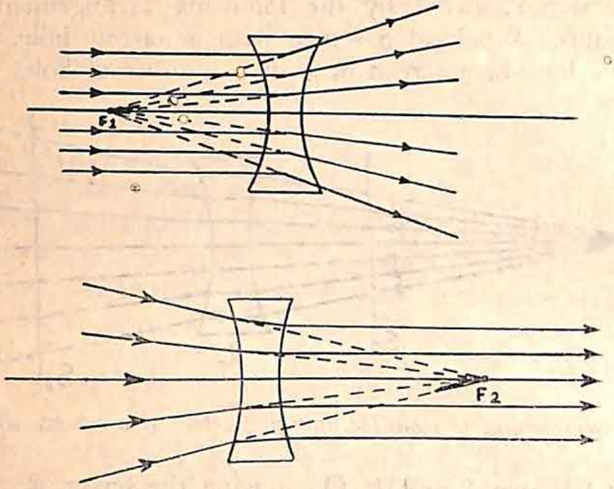


*An arrangement to show the diverging action of a concave lens.*

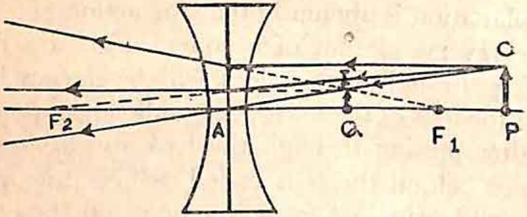
placed between $S$ and $L$. On moving the screen $S_2$ away from the lens it is easily seen that the rays coming out of the lens are diverging. If some smoke is produced around the lens the paths of the rays will be clearly visible.

The explanation is obviously that the action of a concave lens is the reverse of that of a convex lens and therefore rays passing through such a lens will be deviated further away from the axis of the lens. A bundle of rays parallel to the axis after passing through the lens appears to diverge from a point behind the lens called its first principal focus and the second principal focus is a point on the other side of the lens, such that a bundle of rays converging towards that point are refraced by the lens so that they travel parallel to the axis.

The graphical method used in the case of convex lenses can also be used for finding the position, magnitude and nature of an image formed by a concave lens of an object at a given distance from it. We give one instance of it. The rays 1, 2, 3, are respectively parallel to the axis, directed towards $F_2$ and passing through the centre of the lens;



*To show the first principal focus ($F_1$) of a concave lens and the second principal focus ($F_2$).*



*When the object is just beyond the first principal focus of a concave lens, the image is virtual, erect, diminished and situated on the same side as the object.*

the three corresponding refracted rays when produced backwards appear to come from *I* which is therefore the image of *O* as would be seen by the eye receiving the refracted rays 1, 2, and 3. The image of *PO* is *QI* : it is virtual, erect and diminished.

Before concluding this study of lenses we should mention that in many practical cases it is found more useful to work with a combination of two or more lenses, concave or convex, either in contact or at some distance from each other. In the above discussion on lenses we have also greatly idealised their performance, in particular their focussing power. A large bundle of rays coming from one point, after passing through a lens, convex or concave, does not exactly come to a point, or appear to come from a point ; these refracted rays do not all meet exactly at a point, but their points of intersection are spread over a tiny little area, hence the image formed by a lens will not be absolutely sharp: this is referred to as the defects or aberrations of a lens. It is the work of opticians to design lenses of special shapes or combinations of lenses for which these defects are minimised.

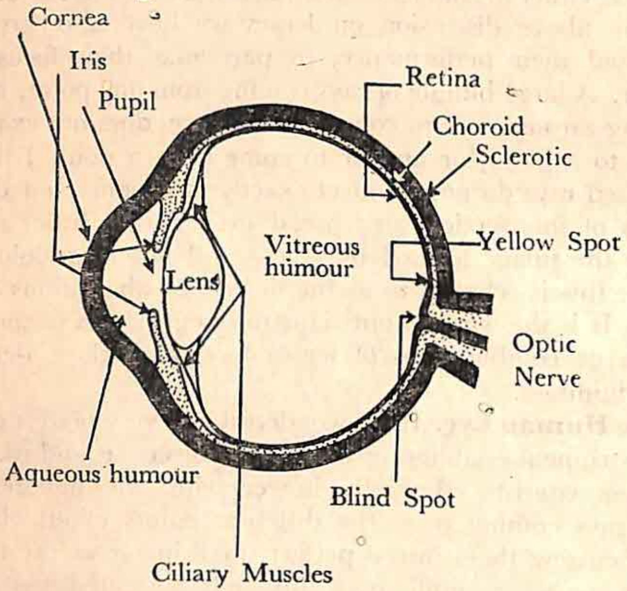
**The Human Eye.** It is a wonderful and very perfect optical instrument enabling us to see the objects around us. Its function consists essentially in receiving the bundles of light rays coming from the different points of an object and focussing them into a perfect small image at the back of the eye where millions of tiny cells are acted upon by the intensity and colour of the light at the various points of the image. These cells are in communication with the optic nerve, which then transmits these impressions to the brain.

**Description of the Human Eye.** The eye-ball is nearly spherical in shape. It bulges a little in front. The wall of the eye is made up of three layers: the sclerotic, the choroid and the retina.

The sclerotic is a strong opaque fibrous membrane extending over the whole of the ball with the exception of a transparent portion in the front which is called the cornea.

The choroid is a dark brown membrane lining the inside of the sclerotic. It consists of a network of blood vessels.

An important function of the choroid is to darken the chamber of the eye, and thus prevent internal reflection of light which would otherwise cause confusion of images



*Section of the human eye.*

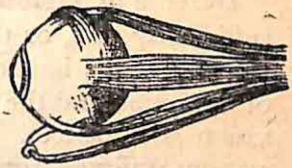
and result in imperfect vision. At the front the choroid merges into the iris which has a variable aperture called the pupil.

The innermost coat of the eye is the retina. It consists of a large number of minute bodies placed side by side. These bodies are sensitive to light impressions. Exactly opposite the centre of the pupil is a spot on the retina called the yellow spot. This is the spot of most distinct vision and the spot on which the image of an object must be focussed in order to be seen clearly as in the case of special work such as reading, writing and sewing. A few millimetres lower down is a spot called the blind spot which is not sensitive to light impressions. Nerve fibres from all parts of the retina collect here to form the optic nerve which transmits light impressions to the brain.

Let us now consider the apparatus concerned with the transmission of light to the retina. Just behind the pupil is a doubly convex body of transparent tissue called the crystalline lens. It is kept in position by a strong elastic frame called the suspensory ligament. The chamber between the cornea and the lens is called the anterior chamber and contains a fluid called aqueous humor. The chamber lying at the back of the lens is called the posterior chamber and contains a jelly-like material called vitreous humour.

The movement of the eye is brought about by the contractions of the six muscles attached externally to each eye.

There are also muscles inside the eye itself. The muscles of the iris regulate the size of the pupil and thus control the amount of light which enters the eye. In strong light the muscles of the iris narrow down the pupil so that not too much light enters the eye. Too strong a light has a blinding effect and is bad for the eyes. In dim light the muscles of the iris dilate the pupil so as to allow as much light as possible to enter the eye.



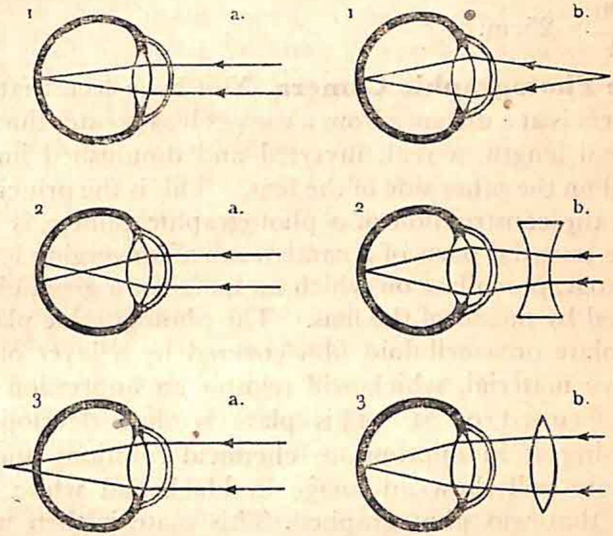
*Muscles of the eye.*

The focussing function of the eye is performed by the crystalline lens together with the aqueous humour in front of it and the vitreous humour behind it. Since both these humours are contained between curved surfaces, they act like lenses; so that the focussing action of the eye is due to the combination of three lenses in contact. However, most of the focussing is done by the crystalline lens, this is a convex lens but the curvature of its faces can be varied within certain limits by the contractile action of the ciliary muscles all around it. In this way even when objects are at different distances from the eye a sharp image can be formed on the retina by the adjusting action of the crystalline lens. This property of the lens is called accommodation. If we look at a distant object, the ciliary muscles relax and the lens becomes less convex. If we turn from the distant object and immediately look at a near one, the ciliary muscles contract and the lens becomes more convex. However, this accommodation is only possible within certain limits; in the case of a normal human eye the closest distance at which an object can be seen distinctly is about twenty-five centimetres or ten inches, and the furthest distance of distinct vision is infinity : this is the range of accommodation for a normal eye. Eyes for which the range of accommodation is different are called defective eyes.

**Defects of Vision.** In some cases the lens cannot be made sufficiently thin, or the eyeball is a little too long, with the result that the image of a distant object is formed in front of the retina and the image on the retina is out of focus and vision is imperfect. This condition is called myopia and persons suffering from it are said to be short-sighted. Myopia can be remedied by wearing concave lenses of suitable power which cause rays of light to diverge or to become less convergent.

The converse condition called hypermetropia is also found, where the lens cannot be made sufficiently thick or the eyeball is too short from front to back. In such cases only distant objects can be seen clearly whilst near objects are imperfectly focussed on the retina. Hypermetropia can be remedied by wearing convex lenses of suitable power which cause rays of light to converge or become less divergent.

With advancing age the crystalline lens loses its elasticity and consequently the power of accommodation is diminished. As a result of this condition, called presbyopia, the retina does not receive sharply defined images of near objects. This condition can also be remedied by the use of convex lenses.



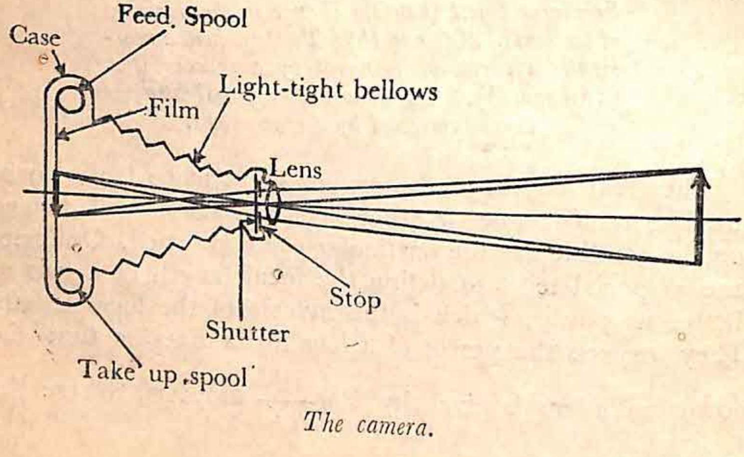
*1 (a). Normal eye receiving parallel rays from distant objects. 1 (b). Normal eye receiving rays from near object (note the change in the thickness of the lens). 2(a) and (b). To show how a near-sighted eye can be corrected by a concave lens. 3(a) and (b). To show how a far-sighted eye can be corrected by a convex lens.*

The focal lengths of the convex or concave lenses to be used to remedy one or other defect of vision will depend on the condition of the particular eye concerned. Opticians use a special term to define the focal length of a lens or better its power, which is the inverse of the focal length. They express the power of a lens in diopters, so that the power of a lens is given by $P=\frac{100}{f}$ diopters, where the focal length $f$ is expressed in centimetres; the power is negative in the case of concave lenses. Thus a lens of which the power is —4 means a concave lens of focal length $f = \frac{100}{4} = 25\text{cm}.$

**The Photographic Camera.** You have seen that when an object is at a distance from a convex lens greater that twice the focal length, a real, inverted and diminished image is formed on the other side of the lens. This is the principle on which the construction of a photographic camera is based.

The essential parts of a camera are a converging lens and a photographic plate on which an image of a given object is focussed by means of the lens. The photographic plate is a glass plate or a celluloid film covered by a layer of light-sensitive material, which will register an impression of the image focussed on it. This plate is then developed by immersing it in appropriate chemical solutions and then the plate will show an image in black and white of the object that was photographed. This plate is then used to make copies of the photograph.

The lens is fixed at the front of a closed box and the



*The camera.*

photographic plate at the back. The box is closed to keep out all stray light which would otherwise befog the photographic plate. In most cameras the sides of the box are flexible so that the distance between the lens and the plate can be slightly varied, because, as you know, with a given lens, the distance at which the image is focussed depends on the distance of the object from the lens. In case of a rigid box camera only distant objects can be focussed, the distance between the lens and the plate being the focal length, because only objects distant about 20 ft. or more will be sharply focussed at the focus of the lens.

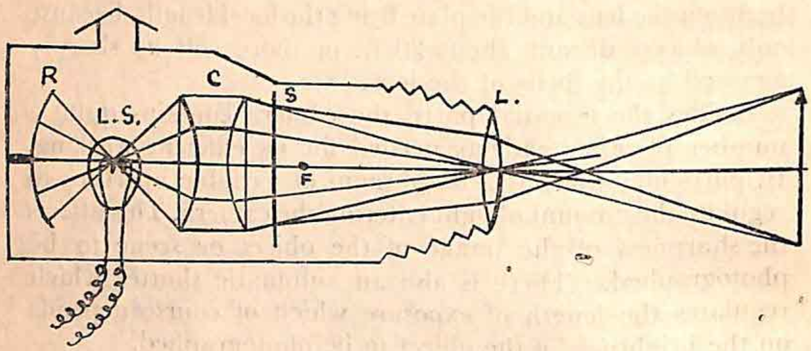
Besides the essential parts, the camera contains quite a number of other gadgets needed for its efficient working. In particular there is a diaphragm of variable aperture to regulate the amount of light entering the camera. This affects the sharpness of the image of the object or scene to be photographed. There is also an automatic shutter which regulates the length of exposure which of course depends on the brightness of the object to be photographed.

**The Projecting Lantern (Magic Lantern).** This instrument is used to project on a screen, by means of a convex lens, a greatly enlarged image of a figure or diagram drawn on a transparent glass plate or film, strongly illumined from the back.

As you have seen, if an object is placed just a little beyond the focus of a convex lens a real inverted and greatly enlarged image is formed at a great distance on the other side of the lens.

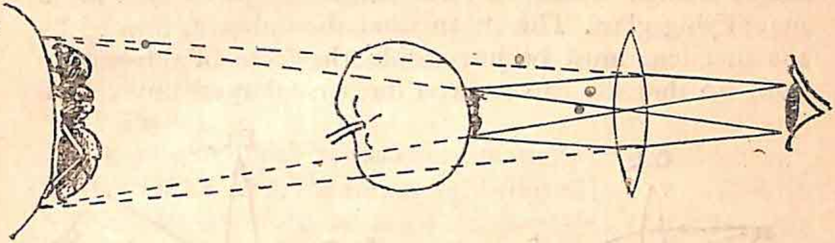
A magic lantern consists of a rectangular box containing a powerful light source, which may be an electric arc, a powerful bulb with a short filament, or an acetylene burner. At the back is a concave reflecting mirror of which the centre of curvature coincides with the centre of the light-source. In this way all the light travelling back from the source is returned along the same path in the forward direction.

All the rays from the source proceeding forward are concentrated by means of the condenser *C*, on to the slide *S*. The figure on the slide *S*, being at a distance from the projecting lens *L* slightly greater than its focal length, this lens will form a greatly enlarged, inverted image on a distant screen *P*. Of course in order to have an erect figure at *P* the slide must be placed with the figure on it upside down.



*The magic lantern.*
*C, condensing lens ; F, focal point of objective lens ; L, objective lens; L.S., light source; P, screen; R, reflector; S, slide.*

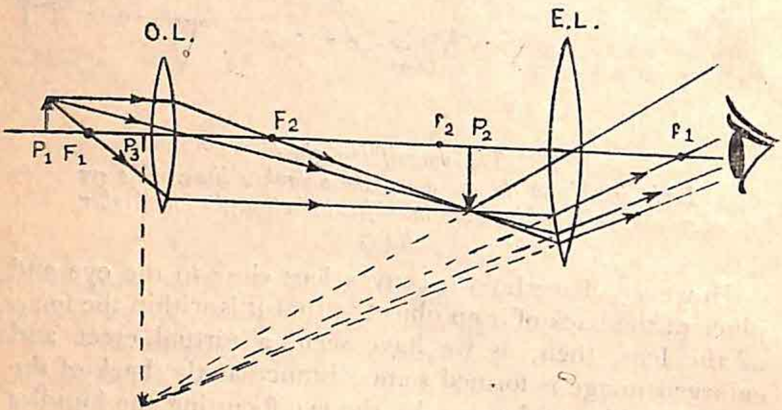
**The Magnifying Glass.** In order to study the details of an object we hold it as close as possible to the eye. However, in the case of a normal eye, even when straining the eye muscles the object begins to look very indistinct and hazy if its distance from the eye is less than about 8 inches. The reason for this is the limits of accommodation of the eye, as mentioned before : the curvatures of the crystalline lens can be altered within limits so as to focus distinctly on the retina, objects at various distances. But as mentioned above, 10 inches is about the nearest distance of distinct vision, and this can be slightly decreased by squeezing the eye so that the eyeball itself is slightly elongated.



*The magnifying glass.*
*Light travels to the eye along the unbroken lines. The eye sees the enlarged image of the object as indicated by the broken lines.*

However, if we hold a convex lens close to the eye and place at the back of it an object so that it is within the focus of the lens, then, as we have seen, a virtual, erect and enlarged image is formed some distance at the back of the lens, and this can be seen by the eye focussing the bundles of diverging rays passing through the lens. The lens and object may have to be moved a little until a clear, enlarged image is seen, because this image will only appear as distinct to the eye if its distance from the eye is about 10 inches or more.

**The Compound Microscope.** With a magnifying glass, magnifications up to about fifteen times can be readily obtained, provided specially good lenses are used. For greater magnification, in case very small objects are to be observed the compound microscope is used, which is essentially a combination of two convex lenses a certain distance apart. The lens nearer the object, called the objective, has a very short focal length, a few millimetres only. The other lens near the eye, called the eyepiece, has a focal length of a few centimetres. The object is placed in front of the lens just beyond its focus so that a real, inverted and enlarged image is formed at a certain distance on the other side of the lens. This image is then observed through the eyepiece used as a magnifying glass. This means that the image as formed by the first lens must be just within the focus of this second lens, so that the lens forms a further enlarged but virtual



*A compound microscope.*
*O.L., objective lens; E.L., eyepiece lens; $F_1$, $F_2$, principal foci of objective; $f_1$, $f_2$, principal foci of eyepiece; $P_1$ object; $P_2$, image formed by objective; $P_3$, final image as viewed through eyepiece.*

image, which is then viewed by the eye placed just behind the eyepiece.

The objective and eyepiece lenses are fixed in tubes that can slide into each other so that the distances between the two can be adjusted to realise the above conditions.

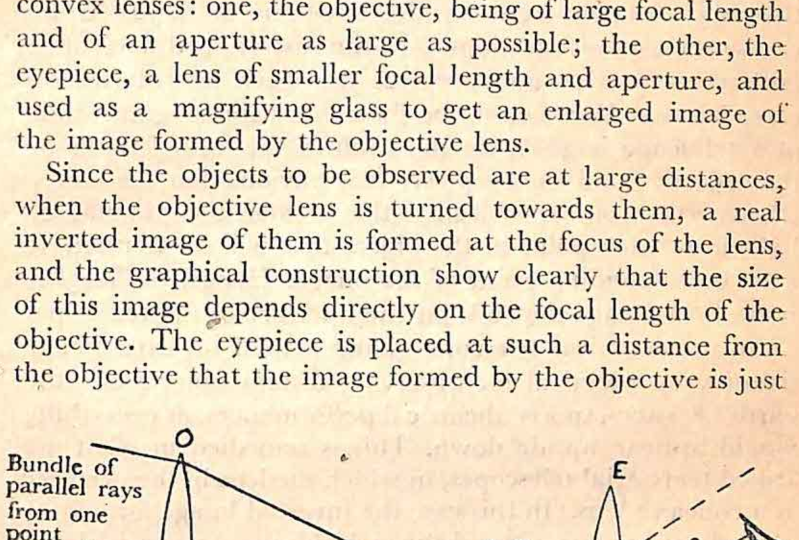
The objective lens has a very small aperture, whereas the eyepiece has a somewhat larger aperture. In good microscopes, meant to give large magnifications up to several hundreds, both the objective and eyepiece consist of sets of two or more lenses to minimise the defects of lenses.

**The Astronomical Telescope.** This instrument is meant to produce clear and distinct images of very distant objects.

For this two conditions are to be realised. The image produced should be as large as possible so that it can be studied in detail, and the image should be as bright as possible otherwise it will be difficult to study it in detail or to photograph it.

An astronomical telescope essentially consists of two convex lenses: one, the objective, being of large focal length and of an aperture as large as possible; the other, the eyepiece, a lens of smaller focal length and aperture, and used as a magnifying glass to get an enlarged image of the image formed by the objective lens.

Since the objects to be observed are at large distances, when the objective lens is turned towards them, a real inverted image of them is formed at the focus of the lens, and the graphical construction show clearly that the size of this image depends directly on the focal length of the objective. The eyepiece is placed at such a distance from the objective that the image formed by the objective is just


O
Bundle of parallel rays from one point of the distant object
E
$F_1$ $F_2$
$f_2$
$P_1$
$P_2$

*The astronomical telescope.*
*E, eyepiece; O, objective;* $F_2$, *focus of objective;* $f_1$, $f_2$, *foci of eyepiece;* $P_1$, *image formed by objective;* $P_2$, *final image viewed through eyepiece.*

within the focus of the eyepiece, so that rays from this image after passing through the eyepiece will diverge and appear to come from a further enlarged virtual image on the same side of the eyepiece, and this is the image viewed by the eye placed behind the eyepiece.

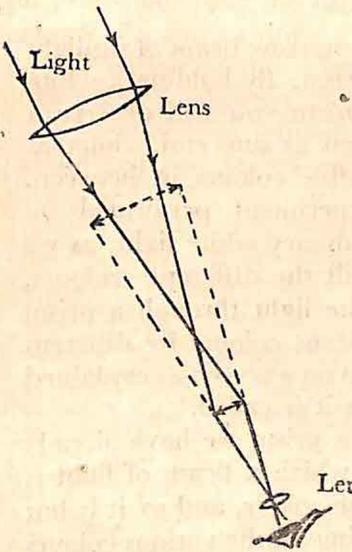
The objective and eyepiece are fitted in sliding tubes so that the distance between the two can be adjusted to realise the above conditions. In the case of good telescopes both the objective and eyepiece are each sets of two or more lenses. It can easily be shown that the magnification of a telescope is given by the ratio of the focal lengths of the objective and the eyepiece. It is obvious that the larger the aperture of the objective the greater the amount of light from each point in the object that will be focussed at each corresponding point of the image. Hence, the brightness of the image depends on the aperture of the telescope.

An astronomical telescope giving a final inverted image is not very practical for observing distant objects on the earth i.e. races, sports, theatrical performances, as everything would appear upside down. This is remedied in what are called terrestrial telescopes, in which the lens in the eyepiece is a concave lens. In this case the inverted image formed by the telescope when viewed through this concave lens, placed at the proper place, will appear inverted once again, so that the final image will be seen as an erect image of the original object.

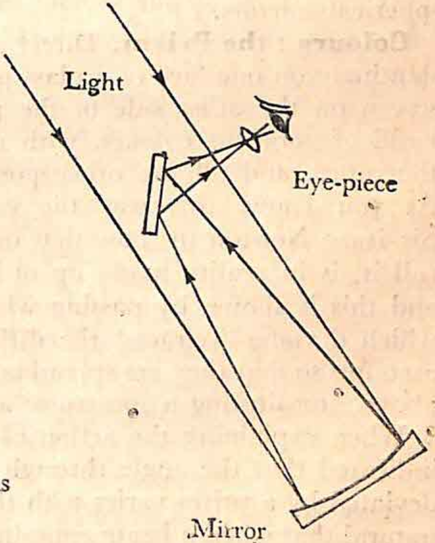
As mentioned above, the light gathering power of a telescope depends on the aperture of the objective lens. In the case of stars and nebulae at enormous distances from the earth, if a sufficiently bright image is to be obtained that can be seen, or at least photographed by an exposure of possibly a few hours, it is necessary to use very large objective lenses and of large focal length, in order to have also a sufficiently large image. Hence the tendency to construct telescopes of ever-increasing apertures and focal lengths.

At present the largest telescope of such a kind is the Yerkes telescope in the United States of America with an aperture of 40 in. and a focal length of 65·3 ft. This appears to be the limit for refracting telescopes because to construct still larger lenses does not seem practicable. In order to have still larger apertures, use is made of concave reflecting mirrors, which can be more easily constructed. The Wilson Observatory in California (U.S.A.) has a reflecting telescope of 100 in. diameter and focal length 42·3 ft., and the Palomar Observatory, also in California, has a reflecting telescope of 200 in. diameter and focal length 55 ft. The latter is at present the most powerful telescope in the world, its light gathering power is equivalent to that of over half a million eyes.

A reflecting telescope functions in a manner similar to that of the refracting telescope explained above. The



*The refracting telescope.*

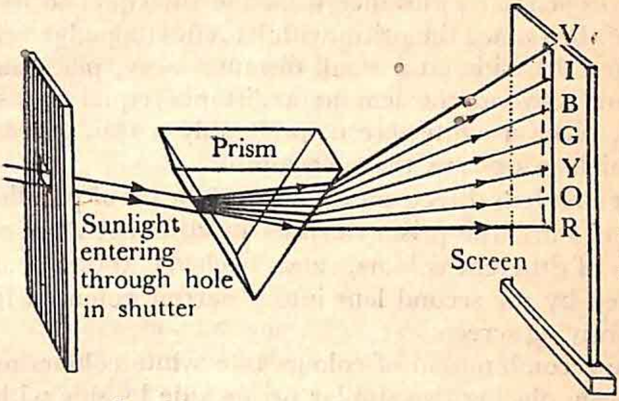


*The reflecting telescope.*

parallel beams of light from each of the points of the very distant object are focussed by the mirror at various points and form an image at the focus of the mirror, its size depending directly on the focal length of the mirror. This image is then further magnified by observing it through an eyepiece which acts as a magnifying glass. In the case of a reflecting concave mirror the image is formed on the same side as the incoming rays, therefore it would be difficult to observe the image with an eyepiece without obstructing the incoming rays. For this reason the rays after reflection at the mirror when coming near the focus are reflected sideways by a plane mirror at 45° to the axis of the telescope, and so the image is formed to one side of the telescope where it can easily be viewed through an eyepiece or photographed if so desired. As mentioned before, in these giant reflecting telescopes the reflecting mirrors are parabolic mirrors which have better focussing properties than spherical mirrors.

**Colours : the Prism.** Direct a narrow beam of sunlight slantingly on one face of a glass prism. By holding a white screen on the other side of the prism you will observe a band of gorgeous colours, with red at one end, violet at the other, and all the other possible colours in between. As you know, this was the experiment performed by Sir Isaac Newton to show that ordinary white light, as we call it, is in reality made up of all the different colours, and this is shown by passing white light through a prism which deviates (refracts) the different colours by different amounts so that they are spread out on a screen as explained above, constituting a spectrum, as it is called.

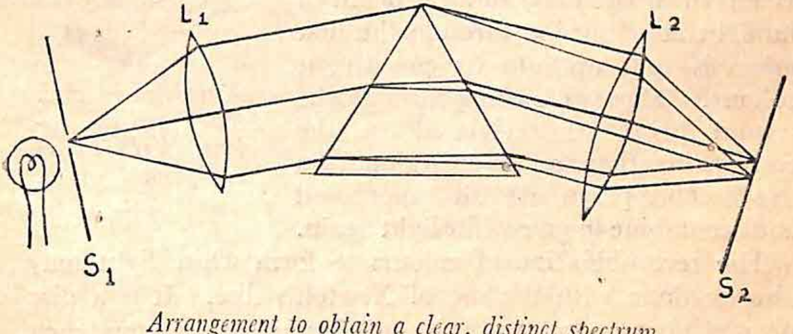
When explaining the action of a prism we have already indicated that the angle through which a beam of light is deviated by a prism varies with the colour, and so it is but natural that when a beam containing all the various colours is incident on one face of a prism at a given angle, the



*Forming a spectrum from sunlight.*
*VIBGYOR denotes the initial letters of the colours comprising the spectrum.*

various coloured beams will be deviated by different amounts on emerging from the other face of the prism and so the colours are spread out or, as is usually said, are dispersed by the action of the prism.

In order to obtain a clear and distinct spectrum the best arrangement is as follows. Place a strong source of light behind a screen $S_1$, with a long narrow vertical slit. Place

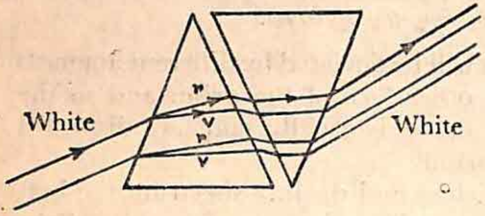


*Arrangement to obtain a clear, distinct spectrum.*

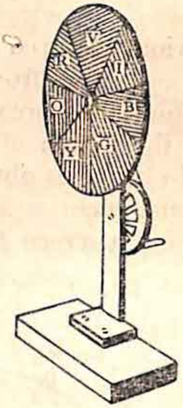
a convex lens at a distance from the slit equal to its focal length, then place the prism with its refracting edge vertical. On the other side, at a small distance away, place another lens and beyond the lens at a distance equal to its focal length place a white screen, preferably a transparent one, on which to observe the spectrum.

The first lens directs on the prism a beam of parallel rays of all colours, the prism deviates by different amounts the beams of different colours, and each of these beams is focussed by the second lens into a narrow coloured line on the receiving screen.

The recombination of colours into white colours may be shown by placing two similar prisms side by side with their refracting edges in opposite directions, as shown in the diagram. A beam of sunlight after passing through the first prism is split up into its constituent colours. These on passing through the second prism are deviated in the reverse direction and on emerging from this second prism are all superposed and recombine to give white light again.



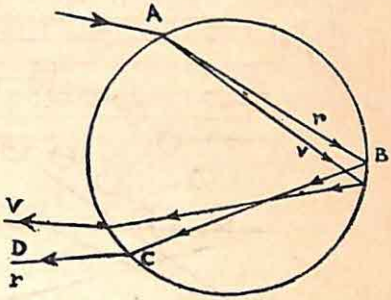
*Recombining the spectrum colours.*



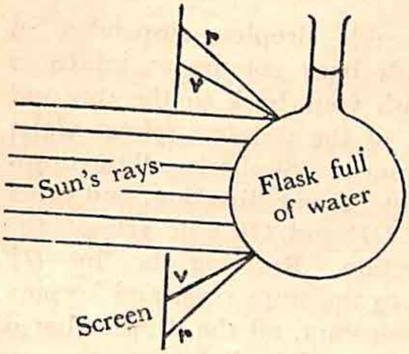
*Newton's disc. The spectrum colours (VIBGYOR) are painted on the disc.*

The recombination of colours to form white light may also be done with the use of Newton's disc. It is a disc pivoted about a central axis and divided into sectors each painted with one of the colours of the solar spectrum. On rotating the disc rapidly about its axis, the colours of the disc appear to diffuse into each other and produce a sensation of greyish-white colour.

**The Rainbow.** You may have observed the sparkling colours of tiny water drops hanging from leaves, wires or cobwebs when the sun comes out after the rain or breaks through the morning fog. This dispersion of the colours of the sunlight by each tiny droplet is mainly an effect of refraction. A ray of light falling on the drop at *A* is refracted along *AB*, then reflected at the back of the drop along *BC*, and at *C* is refracted along *CD* on passing out of the drop. As we know, the degree of deviation of refraction at *A* and *C* varies with the colour : a set of coloured rays emerge at *C* and proceed in slightly different directions. This can easily be demonstrated by holding a round bottomed flask full of water in the sun's rays passing through a circular aperture in a screen, as shown in the diagram. On entering the flask the rays proceed as described above, and therefore on emerging will spread out and form a series of colour-



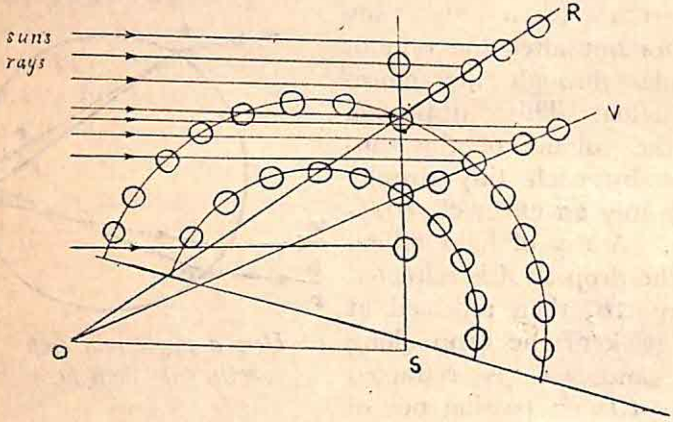
*How a single rain drop splits up sunlight.*



*How a flask filled with water may be used to produce a spectrum.*

ed rings on the side of the screen facing the flask. This is the principle of the formation of the rainbow.

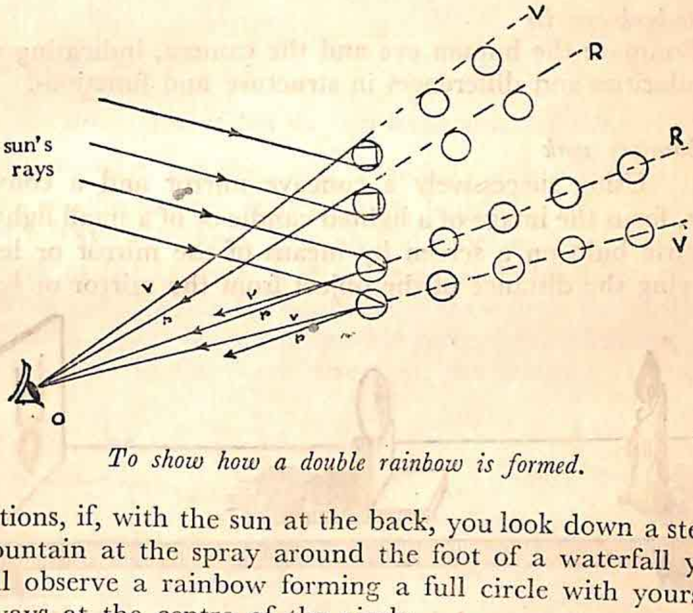
A rainbow is only observed when there is plenty of moisture in the air in the shape of tiny water drops, and when the sun is at the back of the observer. Facing the



*How raindrops acting like prisms split up sunlight to form the rainbow.*

observer there are innumerable droplets suspended in the air, each of which sends back colours as indicated above. If you are at *O* with your back to the sun and looking along the line *OV*, all the droplets refract violet light along *VO* as explained above. Similarly, all the droplets along *OR* refract red light in your direction, and other droplets along lines between *OV* and *OR* will refract the other colours in your direction. Rotating the line *OV* about *OS*, which is parallel to the sun's rays, and keeping the angle between the two constant, all the drops situated along these directions will refract violet light towards you, and so also for the other line *OR* and the lines in between. Therefore, from your point of observation you will see in the sky a series of concentric coloured areas, violet below and red on top with all the other colours in between. At times a second rainbow is observed on top of the first with the order of the colours inverted, this is explained as being due to the sun's rays undergoing two successive reflections inside the droplet before emerging.

This phenomenon of the rainbow can be observed whenever a very fine spray of water droplets is viewed with the sun at the back of the observer. Particularly in hill



*To show how a double rainbow is formed.*

stations, if, with the sun at the back, you look down a steep mountain at the spray around the foot of a waterfall you will observe a rainbow forming a full circle with yourself always at the centre of the circle.

## CHAPTER ACTIVITIES

*Outdoors*

You can make your own rainbow by standing with your back to the sun and squirting water from a hose-pipe in the form of a fine spray against a dark background of trees. The best time to do this is the early morning or in the late afternoon, when the sun is low on the horizon and especially when a strong breeze is blowing, which spreads out the spray into a very fine one.

*For your wall newspaper*

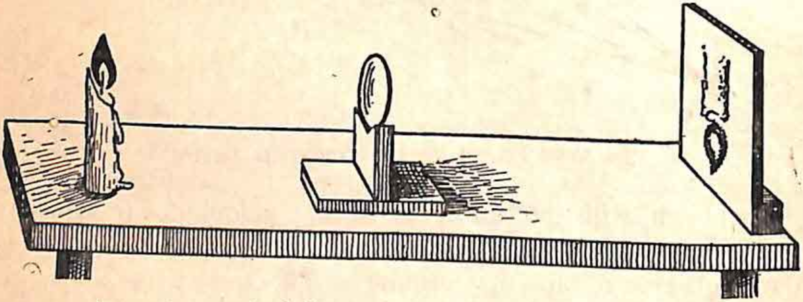
Copy the drawings on page 109, illustrating the spectrum in colour.

*Note-book exercise*

Compare the human eye and the camera, indicating the similarities and differences in structure and functions.

*Laboratory work*

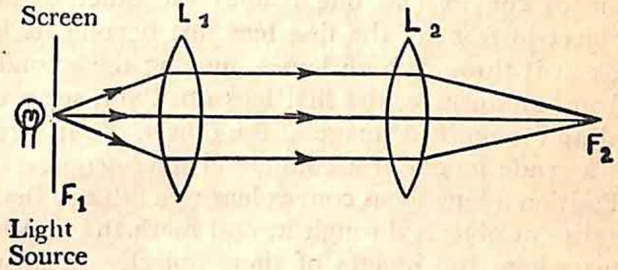
1. Using successively a concave mirror and a convex lens, focus the image of a lighted candle or of a small lighted electric bulb on a screen by means of the mirror or lens, varying the distance of the object from the mirror or lens.



*Apparatus required for performing experiments with mirrors and lenses.*

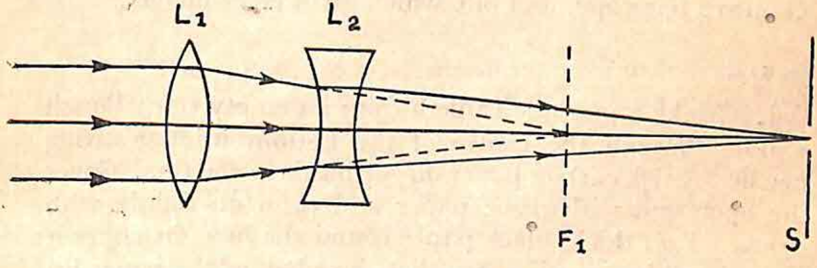
Put down in tabular form against the distance of the object from the mirror or the lens, the distance of the image from the mirror or lens and note whether it is inverted or erect whether smaller or larger. Determine independently the focal length of the mirror or lens and express the above distances by comparison with the focal length (greater than, equal to, or smaller than the focal length).

2. Using two convex lenses, place a source of light *S* at the focus of the first, and receiving the beam of parallel light on the second, find its focal length.



*Arrangement to find the focal length of a convex lens.*

3. Take a convex lens and a concave lens, the focal length of the concave lens being greater than that of the convex lens. Using the convex lens alone focus the image of a distant object on a transparent screen, then keeping the convex lens in the same place put the concave lens at a



*Arrangement to show principal of the telephoto lens. $L_1$, convex lens; $L_2$, concave lens; $F_1$, focus of convex lens; S, final position of image produced by the combined action of the two lenses.*

certain distance from the convex lens on the side of the screen, and find out how much you have to move the screen to have the image clearly focussed on it. This is the principle of the telephoto lens used in photography.

4. Arrange a short focus lens and another somewhat longer focus convex lens one behind the other. Place a small object in front of the first lens just beyond its focus, and look at it through both lenses, moving the second lens away from, or towards, the first lens until you see a clear, inverted and magnified image of the object. Your arrangement is a crude model of a compound microscope.

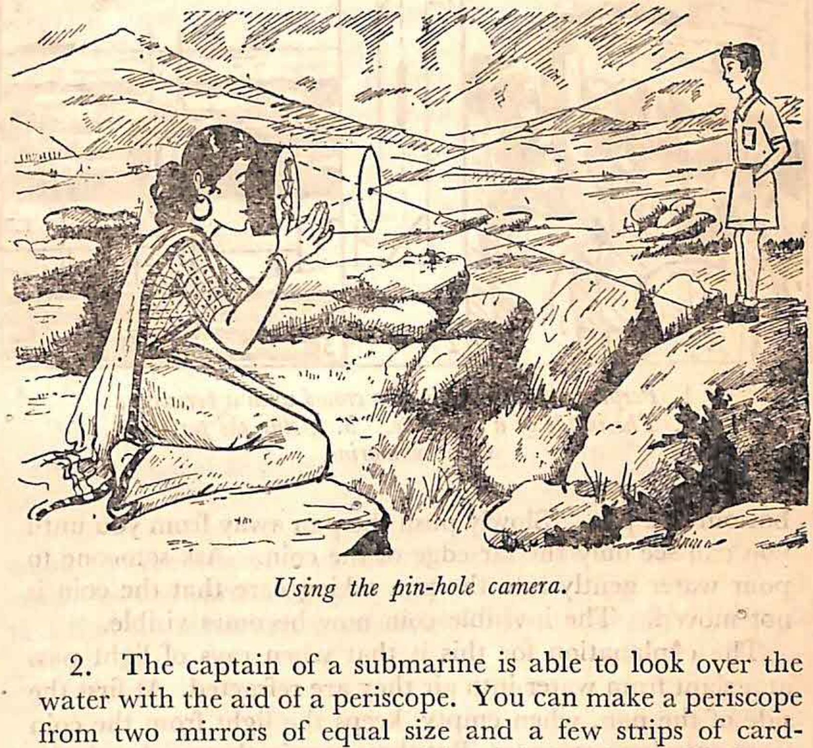
5. Position a long focus convex lens on a table so that you can see distant objects through it, and mark the position of the focus where the images of these objects are focussed. Then place another shorter focus convex lens at a distance just a little less than its focal length from the focus of the first lens and view distant objects through the two lenses. Your arrangement is that of an astronomical telescope.

Now remove the second convex lens and instead take a concave lens and place it at a distance from the first lens just a little less than the difference of the focal lengths of the two lenses, and then view distant objects through this combination. This is a model of a terrestial telescope, called Galileo's telescope, and one which gives erect images.

*At home*

1. Make a pin-hole camera from an empty tin. Punch a hole through the centre of the bottom using a strong needle. Stick carbon paper on the inside of the tin. Cover the open end with tissue paper and tie it on tightly with string. Roll thick, black paper round the box, fastening it on with rubber bands. See that the edges of the paper jut out on one side.

Point your pin-hole camera at a friend and look in from the other side. A picture of your friend standing on his head is seen on the tissue paper. Bearing in mind that light travels in straight lines, it is not difficult to understand why this should happen.

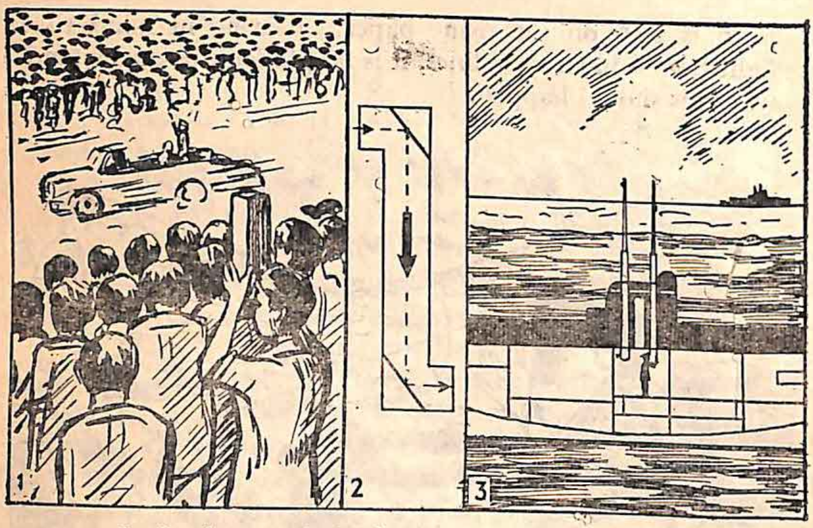


*Using the pin-hole camera.*

2. The captain of a submarine is able to look over the water with the aid of a periscope. You can make a periscope from two mirrors of equal size and a few strips of cardboard. Each mirror is fitted into the cardboard tube at an angle of 45 degrees. Your periscope will come in very handy for peeping over the heads of a crowd.

A periscope can also be constructed by using two right-angled prisms instead of the two mirror-strips. Such a periscope gives brighter views.

3. Strange effects are produced when light travels from one transparent medium into another. Place a coin at the



1. *Peeping over the heads of a crowd with a periscope.* 2. *The inside of a periscope.* 3. *Using the periscope in a submarine.*

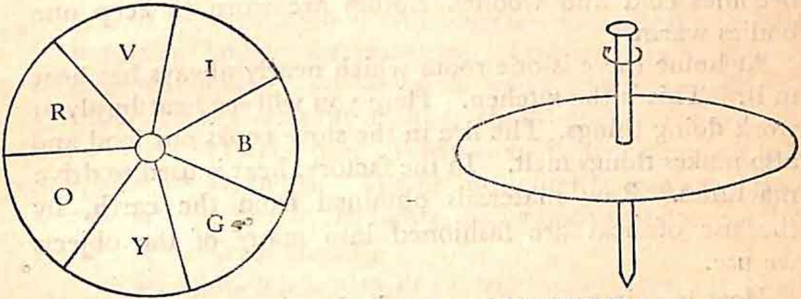
bottom of a pan. Slowly push the pan away from you until you can see only the far edge of the coin. Ask someone to pour water gently into the pan taking care that the coin is not moved. The invisible coin now becomes visible.

The explanation for this is that when rays of light pass at a slant from water into air they are refracted. At first the side of the pan, when empty, keeps the light from the coin from entering your eyes. But the water in the pan bends the light from the coin at the surface making the coin visible. You do not see the coin where it really is as it now appears to be higher up in the pan. It seems to be in a straight line with your eye and the edge of the pan.

4. Make two black spots side by side on a sheet of white paper so that they are separated by a distance of 55 millimetres. Close the left eye and look at the left dot with

your right eye. Hold the paper at a distance of about 30 centimetres and move it slowly towards you. At a distance of about 10 centimetres from your open eye the right dot will suddenly disappear. This is because its image has fallen on the blind spot of your open eye which, as you know, is insensitive to light impressions. On moving the paper still close the dot reappears.

5. Cut a circle out of a piece of cardboard. Divide it into seven equal sectors and paint the sectors the seven



*How to recombine the spectrum colours (VIBGYOR) by means of a top.*

colours of the spectrum as shown. Push a nail through the centre of the card and spin the card as a top. You will find that the seven colours combine to form a greyish white.

## CHAPTER IV

# WHAT HEAT CAN DO

ALL OF US who live in the tropics are familiar with the great heat our land receives from the sun in the summer months. At this time of the year the heat becomes so unbearable that it is most uncomfortable to go outdoors in the afternoon. During the winter months in North India the weather becomes cold and woollen clothes are worn to keep our bodies warm.

At home there is one room which nearly always has heat in it. This is the kitchen. Here you will see heat busily at work doing things. The fire in the stove cooks our food and also makes things melt. In the factory, heat is used to drive machines. Raw materials obtained from the earth, by the use of heat are fashioned into many of the objects we use.

Heat is as important to us as food and water. Life on our earth would stop if there were too little heat or too much of it. It helps us to do many things and can be an obedient slave. In this chapter you will learn what heat can do, how it can be produced, measured, controlled and used economically and effectively to meet the many needs we have for it in our everyday life.

**Sources of Heat.** The problem of producing heat easily has puzzled man through the ages. Today there are many ways of making heat quickly and with no bother at all.

Of all the sources of heat the sun is the most important. Not only does it provide us directly with warmth, but it is also responsible for the growth of plants. You will remember having read in Chapter I that plants are a source of chemical energy from which heat is readily made available.

Heat is produced as the result of chemical action. It is often set free when two substances react together to form new substances. If you put a copper coin into a beaker of nitric acid you will find that the heat produced as the result of chemical action makes the beaker too hot to hold. Another chemical action in which heat is produced is oxidation. When fuels burn in air they do not merely combine with oxygen but give off heat as well. The temperature of our body is due to the combination of fuel foods with oxygen.

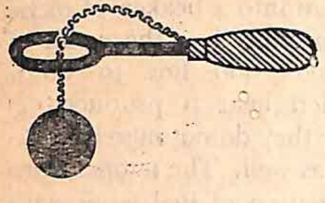
Heat is produced as the result of friction. The fact that heat is produced when two objects rub against each other has been known for centuries. Primitive man started a fire by rubbing two sticks of wood together. The heat produced as the result of the friction between the sticks was sufficient to start a fire. When stone is struck against metal, sparks are given off. The petrol lighter is an application of this fact, the flint in the lighter being nothing but a combination of different metals.

A safety match is also lit by friction. When the head of the match is struck against the match-striking surface of the match-box the friction raises the temperature of the chemicals to a temperature high enough to burst into flame and thereafter sets the wooden stick on fire.

Heat is produced by electricity. When an electric current passes through a wire it heats the wire. You will read more about the heating effect of an electric current in Book IV.

**Expansion of Solids.** All solids expand when heated and contract when cooled. Since they have a definite shape this expansion is noted to be in length, area and volume.

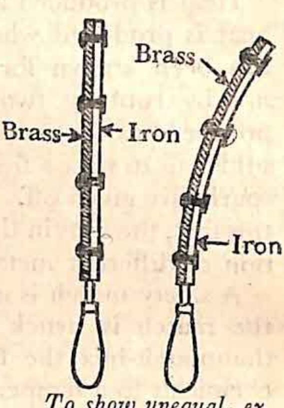
Take the apparatus known as Gravesande's ring. This apparatus consists of a metal ball and ring. The ball is of such a size that it just passes through the ring at ordinary temperature. Heat the ball in a bunsen flame for a few minutes and attempt to pass it through the ring. You will find that since the ball has gained in size it no longer passes



*Gravesande's ring.*

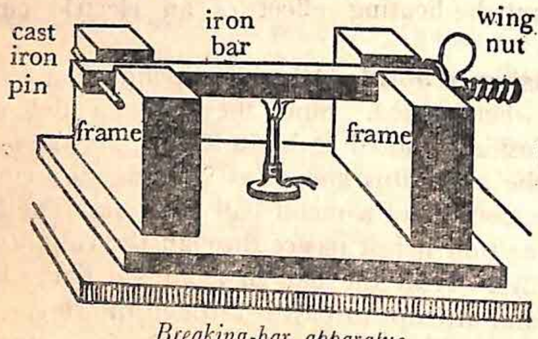
through. Leave it on the ring and allow it to cool. As it cools it contracts until it returns to its original size, and then passes through the ring.

Equal lengths of different solids when heated to the same extent expand by different amounts. This can be shown, in the case of metals, by taking a straight compound bar made up of a strip of brass firmly riveted along its length to a strip of iron, and heating it in a bunsen flame. You will find that the bar becomes curved after a few minutes in the flame. As brass is on the outside of the curve it is evident that it has expanded more than the iron.



*To show unequal expansion of brass and iron.*

In the laboratory you may have an apparatus to demonstrate the enormous force exerted by a solid when opposition is offered to its expansion or contraction. This apparatus



*Breaking-bar apparatus.*

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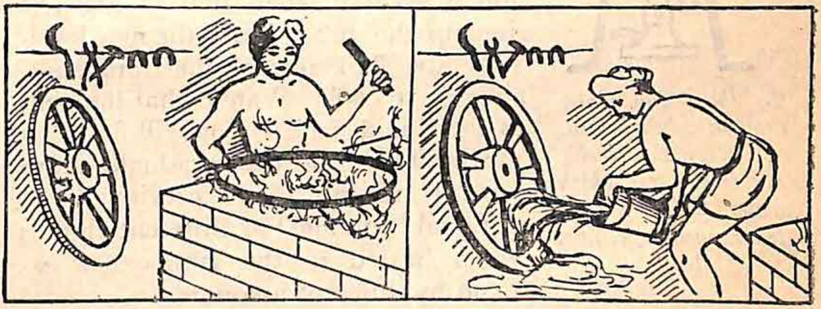
consists of a strong cast-iron frame in which an iron bar rests. At one end of the bar is a screw thread on which turns a nut, while at its other end is a hole through which passes a short cast-iron pin. The bar is heated by a bunsen flame and as it expands the nut is screwed tightly so that the cast-iron rod is kept pressed firmly against the frame. After this procedure has been continued for a few minutes, the flame is removed and the rod is allowed to cool. The iron bar now contracts until finally the force due to its contraction is sufficient to break the cast-iron pin.

The fact that solids expand when heated and contract when cooled has received a number of applications.

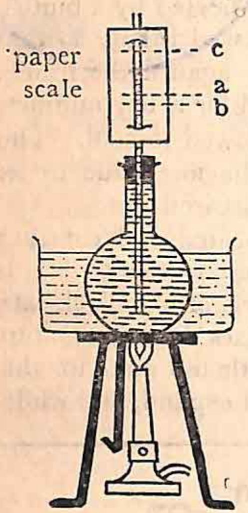
You may have noticed that the wheels of a bullock-cart have iron tyres. The wheelwright, who fixes these tyres on to the wheel, first makes the tyre just a little too small for the wheel. He then heats the tyre to make it expand, and while the tyre is still hot he slips it on to the wheel. He next throws buckets of water on to the metal tyre to make it cool quickly. As the tyre cools it grips the wheels firmly.



*A wheelwright at work.*

When the glass stopper of a bottle becomes so tightly stuck that it is difficult to remove, the bottle neck is cautiously heated to make it expand and thus facilitate the removal of the stopper.

**Expansion of Liquids and Gases.** Liquids and gases expand when heated and contract when cooled. Unlike solids, expansion in such cases is only shown by a change in volume.



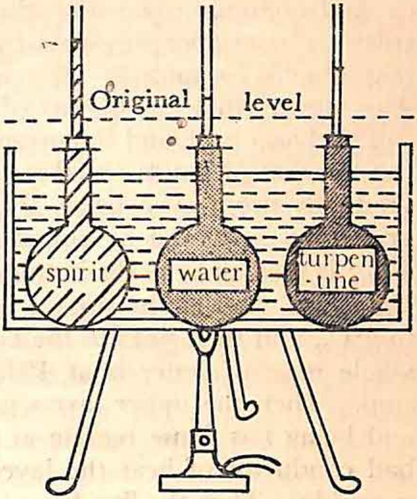
*To show that water expands when heated. a, original level; b, level to which water falls for a few moments; c, final level.*

Take a glass flask and completely fill it with coloured water. Fit a one-holed stopper and glass tube to it so that a little liquid is forced up the tube. Mark the level of water in the tube with gummed paper. Immerse the flask in hot water contained in a trough. You will notice that the level of water in the tube first falls and then begins to rise. When the flask is heated it expands, and this causes the level of liquid in the tube to fall, but as the liquid is heated it expands and since its expansion is greater than that of glass, it rises up the tube. Mark the new level. Take the flask out of the trough and allow it to cool. Watch what happens as the liquid cools. You will find that the liquid in the tube gradually drops until it returns to its previous level.

Equal volumes of different liquids when heated to the same extent expand by different amounts.

Take three glass flasks of the same size and fit each with a one-holed stopper and a glass tube. All the tubes must be of the same length and have the same internal diameter. Fill the first flask with methylated spirit, the second with coloured water and the third with turpentine. Adjust the levels of the liquids in all three tubes so that they are the same. Mark these levels with gummed paper. Place the flasks in a trough and pour water into the trough. Heat the trough. Note that although the liquids expand, they expand by different amounts as indicated by the variation in the heights of the liquid columns. Of the three liquids, methylated spirit expands more than turpentine, and turpentine more than water.

The thermometer is an important application of the fact that liquids expand when heated and contract when cooled.



*To show the different amounts by which liquids expand.*

To show that gases expand when heated and contract when cooled, take a glass flask and fit it with a one-holed stopper and a glass tube. Invert the apparatus over a trough of water so that the tube dips into the water. Slightly warm the flask by means of a bunsen flame. As the air in the flask is heated it expands and bubbles through the water. On allowing the flask to cool, the air remaining in the flask contracts and water is forced into the flask by atmospheric pressure acting on the surface of the water in the trough to take the place of the air which has been expelled.

Unlike solids and liquids all gases expand to the same extent when heated under the same experimental conditions.

Hot air balloons are an application of the fact that air expands when heated. The hot air which fills the balloon has a density less than that of the atmosphere and consequently the balloon rises to a height where the density of the atmosphere is equal to that of the hot air within it.

**Anomalous Expansion of Water.** Whereas most liquids expand continuously with rising temperature, water contracts as its temperature rises from 0°C to 4°C. after which it gradually expands as the temperature is raised further. This means that the density of water is greatest at 4°C.

This has a profound importance in nature with regard to the freezing of ponds or lakes. As the outside temperature gradually drops even below 0°C., the water at the surface gradually cools and so contracts until its temperature is 4°C.; it then sinks to the bottom, and warmer water that is less dense rises to the surface where it also gradually cools to 4°C., and then sinks to the bottom, so that gradually the whole mass of water is at 4°C., when convection currents stop. Then the upper layers gradually cool down further and being less dense remain at the surface. As water is a bad conductor of heat the layers lower down do not cool so rapidly. Thus the first layers to freeze are the top layers, and as ice is less dense than water, the ice floats. So it happens that below a more or less thick top layer of ice, the water remains practically at 4°C., and all the animal and plant life inside and at the bottom of the pond or lake is safe.

If, on the contrary, water were steadily expanding from 0°C. upwards, it is the water at the bottom, being densest, that would have frozen first, and thus the water would have frozen solid from the bottom upwards.

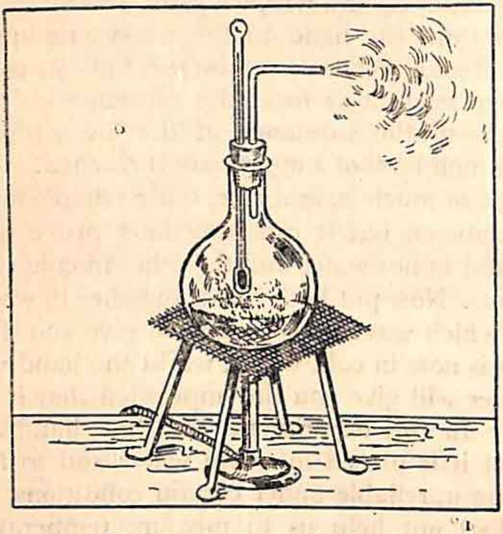
**Temperature and Heat.** The temperature of a substance is a measure of its 'hotness' or 'coldness'. Temperature does not tell us the amount of heat contained in a substance, but it does tell us how hot or cold a substance is. A lump of lead weighing 100 pounds has twice the amount of heat in it as compared with a lump of lead weighing 50 pounds, but both the lumps have the same temperature.

We usually rely on our sense of touch to tell us whether a substance is hot or cold. If we put a hand in hot water heat flows from the water to the hand and produces a sensation of warmth. If, however, we place a hand in cold water heat flows from the hand to the water and produces a sensation of cold. When two substances are in contact with one another heat flows from the substance at the higher temperature to the substance at the lower temperature, until a common level of temperature is reached.

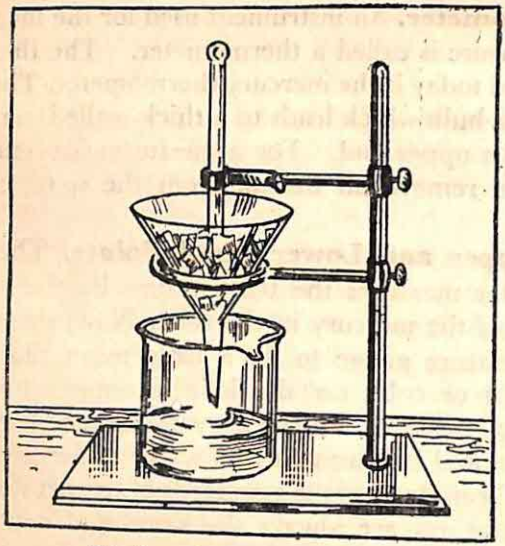
Our sense of touch is, as a rule, quite reliable for comparing temperatures, but it can sometimes prove misleading. Put one hand in hot water and the other in cold water for a few moments. Now put both hands together in warm water. The hand which was in hot water will give you the impression that it is now in cold water, whilst the hand which was in cold water will give you the impression that it is now in hot water. In this experiment the 'hot' hand loses heat the moment it is placed in warm water and so feels cold. Besides being unreliable under certain conditions, our sense of touch does not help us to measure temperature or a change of temperature accurately.

**Thermometer.** An instrument used for the measurement of temperature is called a thermometer. The thermometer widely used today is the mercury thermometer. The mercury is in a glass bulb which leads to a thick-walled, narrow tube sealed at its upper end. For accurate measurements, it is essential to remove all the air from the space above the mercury.

**The Upper and Lower Fixed Points.** The mercury thermometer measures the temperature by the amount of expansion of the mercury in the tube. Now, since we want our temperature gauge to do a little more than merely indicate hot or cold, certain definite temperatures are to be taken as standards. In the measurement of temperature, the freezing and boiling points of water under given conditions have been fixed as the standards of temperature. These two temperatures are always the same and can be easily found.



*Finding the upper fixed point.*



*Finding the lower fixed point.*

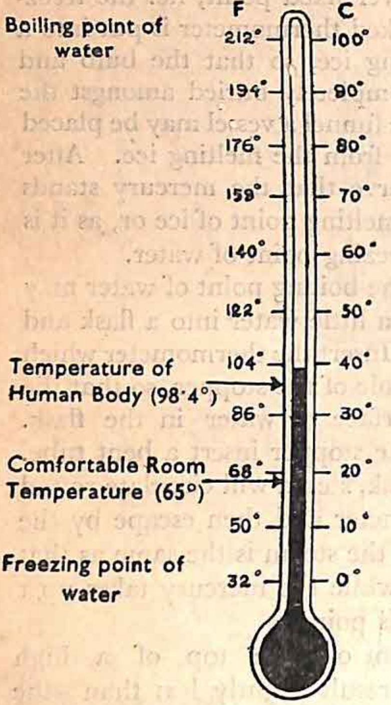
In order to determine the lower fixed point, i.e. the freezing point of water, the unmarked thermometer is put into a funnel containing pure melting ice, so that the bulb and lower part of the stem are completely buried amongst the pieces of crushed ice. Below the funnel a vessel may be placed to collect the water that drips from the melting ice. After several minutes you will observe that the mercury stands at a constant level. It is the melting point of ice or, as it is more frequently called, the freezing point of water.

The upper fixed point, i.e. the boiling point of water may be obtained as follows. Pour a little water into a flask and fit it with a two-holed stopper. Insert the thermometer which was used before through one hole of the stopper, so that the bulb is a little above the surface of water in the flask. Through the second hole of the stopper insert a bent tube. On boiling the water in the flask, steam will circulate round the lower part of the thermometer and then escape by the side tube. The temperature of the steam is the same as that of the boiling water. After a while the mercury takes up a stationary position. Mark this point.

If you repeat this experiment on the top of a high mountain you will obtain a result slightly less than the normal boiling point. This is because the boiling point of water depends on the atmospheric pressure at the place where it is measured. The boiling point of water is therefore, defined as the temperature at which pure water boils under standard atmospheric pressure, i.e. a pressure corresponding to a barometer height of 76 cm. of mercury.

**Thermometer Scales.** Having determined the two fixed points , a scale is put on the stem of the thermometer. This is done by dividing the space between the two fixed points into a number of units called degrees written as°.

There are different ways of dividing the space between the two fixed points. In one kind of thermometer the space is divided into 100 equal parts. Here the freezing point is



*The Centigrade* (*C.*) *and Fahrenheit* (*F.*) *scales as compared with each other.*

marked 0° and the boiling point is marked 100°. The thermometer with this simple arrangement is called the Centigrade thermometer. This thermometer is the one generally used for all scientific purposes.

Another kind of thermometer has the freezing point marked 32° and the boiling point marked 212°. The space between the two fixed points is divided into 180 divisions. A thermometer marked in this way is called the Fahrenheit thermometer.

**Conversion of One Scale into the Other.** You will sometimes find it necessary to convert the reading on one scale into the corresponding reading of the other scale. This may be done by a simple calculation. You have read that,

$$100 \text{ C. divisions} = 180 \text{ F. divisions}$$

$$\text{so } 1 \text{ C. division} = \frac{180}{100} \text{F. divisions}$$

$$= \frac{9}{5} \text{ F. divisions}$$

Since the zero on the Fahrenheit scale is 32 F. degrees below the freezing point of water which on the Centigrade scale is zero degrees, you must first multiply the C. reading by $\frac{9}{5}$ and then add 32.

Thus a temperature of

$$15^\circ\text{C.} = 15 + \frac{9}{5} + 32 \text{ or } 59^\circ \text{ F.}$$

To change a Fahrenheit reading to the corresponding Centigrade reading you must remember that

$$180 \text{ F. divisions} = 100 \text{ C. divisions}$$

$$\text{so} \quad 1 \text{ F. division} = \frac{100}{180} \text{C. divisions}$$

$$= \frac{5}{9} \text{ C. divisions}$$

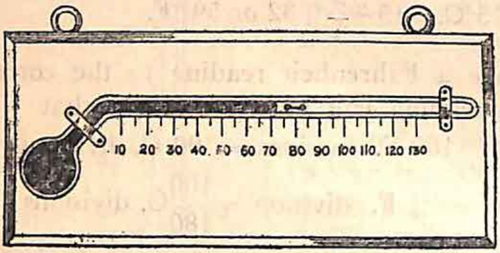
Since the Fahrenheit scale is 32 degrees ahead of the freezing point on the Centigrade scale you must subtract 32 from the F. reading and then multiply the result by $\frac{5}{9}$.

Thus a temperature of $50^\circ\text{F} = (50—32)\,\frac{5}{9}$ or $10^\circ$C.

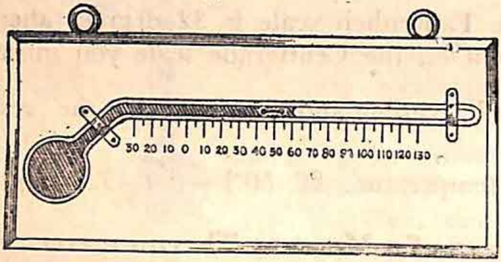
**Advantages of a Mercury Thermometer.** Mercury is particularly chosen to fill a thermometer because it is opaque; it does not wet the sides of the glass; it quickly takes up the temperature of its surroundings as it is a good conductor of heat; its expansion is regular; it only freezes at a very low temperature and boils at a very high temperature.

**Maximum and Minimum Thermometer.** In meteorological observations it is necessary to record the highest and lowest temperatures of the air for every period of 24 hours. It would be inconvenient to use an ordinary thermometer for such a purpose as it would be necessary to observe it continually which is impracticable. Certain thermometers have been specially designed to overcome this difficulty.

The maximum thermometer is merely an ordinary thermometer fixed in a horizontal position to a board. In the bore of the thermometer, beyond the mercury column is a dumb-bell shaped index made of steel. When the temperature rises, the mercury expands and pushes the index forward. When the temperature falls, the mercury contracts leaving the index behind. The end of the index nearest the mercury gives the maximum temperature reached during a certain period of time. The thermometer is re-set by sliding the index back to the end of the mercury column with a magnet.



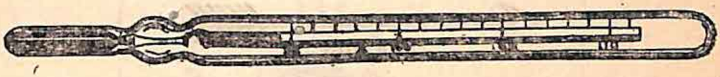
*The Maximum F. Thermometer.*



*The Minimum F. Thermometer.*

The minimum thermometer contains alcohol and is fixed in a horizontal position to a board. The dumb-bell-shaped index is made of black glass and is immersed in the alcohol column. When the temperature falls, the alcohol contracts and the surface of the alcohol column drags the index back towards the bulb. When the temperature rises, the alcohol expands and flows past the index leaving it behind. The end of the index away from the bulb indicates the minimum temperature reached during a certain period of time. The thermometer is re-set by holding it at a slant with the bulb uppermost, thus allowing the index to slide along in the alcohol until it is stopped by the surface of the alcohol.

**The Clinical Thermometer.** The thermometer with which we are all familiar is the one used by the doctor to take our temperature. It is called the clinical thermometer. Since the doctor only requires it for testing the temperature of the human body the scale is graduated between 95°F., and 110°F. which is as cold or hot as a human being can be. Each degree is divided into five equal parts because even small varations in the temperature of a patient are of great importance. The bulb of the thermometer is small, so that it may quickly reach the temperature of the patient's body. The bore of the thermometer is exceptionally fine and has a kink in it. When the mercury is heated, the great force of its expansion pushes it past the kink. As the thermometer is removed from the heat of the patient's body and comes in contact with the cooler air, the mercury contracts. The portion of the mercury below the kink retreats into the bulb whilst the portion of the mercury above the kink stays where it is, as it cannot squeeze its way back through the kink. The thermometer may now be kept until the arrival



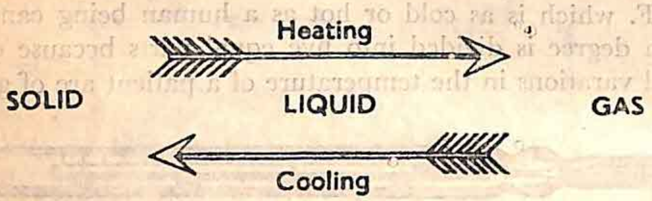
*The Clinical Thermometer.*

of the doctor. Once the reading has been taken, the thermometer is re-set by bringing the mercury in the bore back to the bulb with a jerk.

A person in good health has a temperature of 98·4°F. and there is a mark on the thermometer at this point. A temperature of over 100°F. indicates fever and if the thermometer registers over 105°F. it means that the patient is dangerously ill.

**Change of state.** We have done many experiments showing that heat brings about a change of size and a change of temperature. Besides these two effects heat also brings about a change of state.

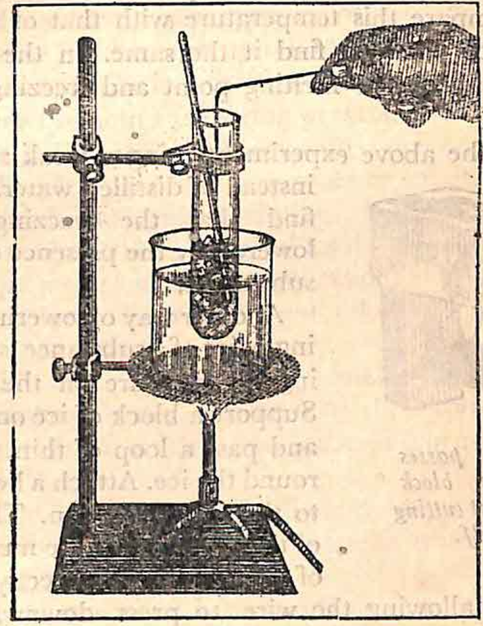
All substances exist in one of three states—solid, liquid or gas. A solid has a fixed shape and a fixed volume : a liquid does not have a fixed shape but it has a fixed volume; a gas has neither a fixed shape nor a fixed volume. A change of state from one form to another is caused by the addition or removal of heat.



We are all familiar with the three states of water. In the solid form it is ice, in the liquid form it is water and in the gaseous form it is steam. We know from everyday experience that if ice is to be changed to water heat must be applied, and if water is to be changed to ice the water must be cooled.

**Melting Point.** The change of a substance from the solid state to the liquid state is called melting and the temperature at which the change takes place is known as the melting point of the substance.

Fill half a test-tube with some pieces of pure ice and insert a thermometer, so that the bulb is completely surrounded by the pieces of crushed ice. Stand the test-tube in a beaker of water and note the temperature. Gently warm the water and constantly stir the contents of the test-tube. You will notice that whilst the ice is melting, the level of mercury in the thermometer remains constant in spite of the fact that heat is being added to the mixture of ice and water during this time. We therefore conclude that during the conversion of ice to water the heat received is used to bring about a change of state. Once all the ice has changed to water the mercury begins to rise.

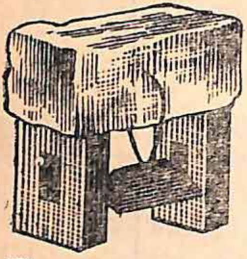


*The temperature at which ice melts, remains the same until all the ice has changed to water.*

The melting point of a substance is lowered by the presence of dissolved substances in it. Repeat the last experiment adding some salt to the ice. The presence of salt lowers the melting point of the ice. Further repetitions of the experiment with the addition of more salt each time will result in the corresponding lowering of the melting point.

Nearly fill a test-tube with distilled water and suspend a thermometer in the water. Stand the test-tube in a beaker containing a mixture of salt and ice. Such a mixture is called a freezing mixture. Stir the water in the test-tube continually and note the temperature at which it freezes. While the water solidifies, its temperature remains unaltered. If you compare this temperature with that of the melting point of ice you will find it the same. In the case of all pure substances, the melting point and freezing point are the same.

Repeat the above experiment using a weak salt solution instead of distilled water. You will find that the freezing point is lowered by the presence of dissolved substances.



*The wire passes through the block ice without cutting it in half.*

Another way of lowering the melting point of a substance is by increasing the pressure on the substance. Support a block of ice on two bricks and pass a loop of thin strong wire round the ice. Attach a heavy weight to the wire as shown. The pressure of the wire lowers the melting point of ice and the ice directly under the wire melts, allowing the wire to press downwards. The water which forms flows round the wire and being free from pressure and surrounded by ice, refreezes above the wire.

**Change of Volume on Solidification.** Whereas most substances contract on solidification, a few expand on solidification. Amongst the latter are ice, cast iron, bismuth and antimony.

In the case of substances which contract on solidification it means that the solid sinks in the corresponding liquid, whereas in the case of expansion on solidification the solid floats, as is clearly seen in the case of ice. The expansion of ice on solidification is about 9 per cent, so that 11 c.c. of water at 0°C. are transformed into 12 c.c. of ice. This means that in the case of icebergs : to the volume of ice above the water corresponds eleven times that volume under the water.

In cold countries water pipes exposed to the extreme cold of the winter will burst on account of the expansion of water when it freezes. The fact that cast iron expands on solidification is very useful in the casting process, because the molten iron poured into the mould expands on solidification and so will fill every part and corner of the mould, resulting in a sharp and well-formed casting.

**Evaporation.** The change of a substance from the liquid to the vapour state is called evaporation. This change of the liquid to vapour is gradual and takes place only at the surface of the liquid.

A liquid evaporates quickly if it is at a high temperature, the atmosphere is dry, the area of the exposed surface is large and there is a breeze to assist in the removal of the vapour as it is formed.

Some liquids such as ether and methylated spirit evaporate more readily than other liquids such as water and coconut oil.

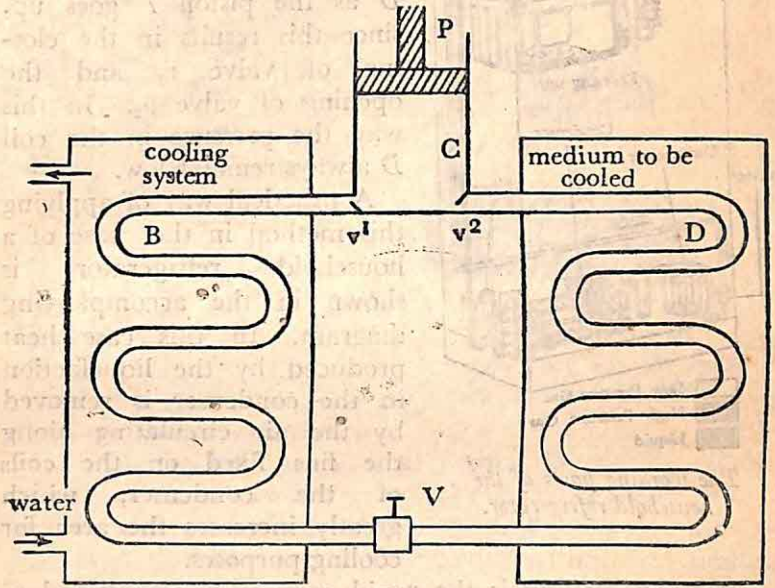
During evaporation heat is taken from the remaining portion of the liquid and from the substance in contact with the liquid. You can easily prove this by means of a simple experiment. Pour some water on a table and put

*By rapidly evaporating the ether in the beaker the water beneath the beaker freeze.*

an empty beaker on it. Next, pour some ether in the beaker and blow a stream of air through the ether with the help of a football pump connected to a rubber tube. After the ether has evaporated, try to remove the beaker from the table. You will find that the beaker is now stuck to the table. Whilst the ether evaporated it took heat away from the bottom of the beaker to such an extent that the water beneath the beaker froze.

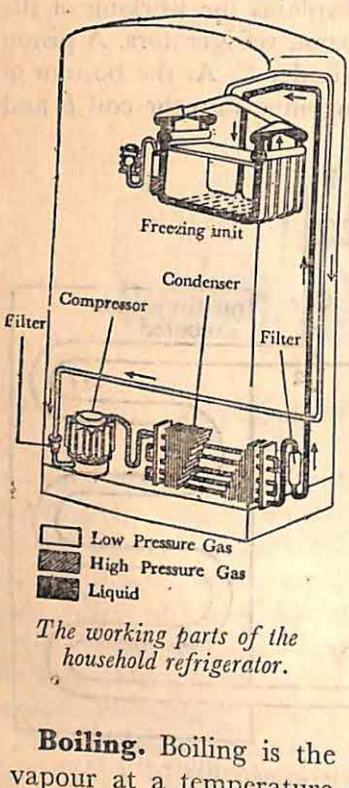
**Refrigerators.** The experiment just described explains the working principle of most refrigerating machines. The change of state of a substance from liquid to vapour requires a large amount of heat, therefore if we can cause the rapid evaporation of liquid, this will absorb large quantities of heat from the surrounding medium, the temperature of which will consequently be greatly lowered. However, to realise a practical way of cooling by rapid evaporation, we must devise a method by which a limited quantity of liquid is repeatedly made to evaporate rapidly and then by compression changed back into liquid, which is then once again made to evaporate rapidly, and so the cycle of operations can be repeated.

The accompanying diagram explains the working of the common type of vapour-compression refrigerators. A piston *P* moves up and down in the cylinder *C*. At the bottom of the cylinder are two valves : $v_1$ opening into the coil *B* and $v_2$ opening into the cylinder *C* connected to the coil *D*. The coils *B* and *D* are connected at the lower portion through a throttle valve *V*. A readily liquefiable gas, like ammonia, carbon dioxide or freon, is used as the refrigerant circulating in the coils *B* and *D*.



*To show the working of the vapour-compression refrigerator.*

When the piston moves down, the valve $v_1$ opens and the valve $v_2$ closes, so that the gas is compressed in the coil *B* where it liquefies. The heat produced in the liquefaction process is removed by a flow of water or air around the coil *B*. The liquid passes slowly through the throttle valve *V* into low pressure coil *D*, where it evaporates and the resulting cooling is transmitted to the air or water surrounding the coil *D*. The expanded vapour is then drawn out of *D* as the piston *P* goes up, since this results in the closing of valve $v_1$ and the opening of valve $v_2$. In this way the pressure in the coil *D* always remains low.

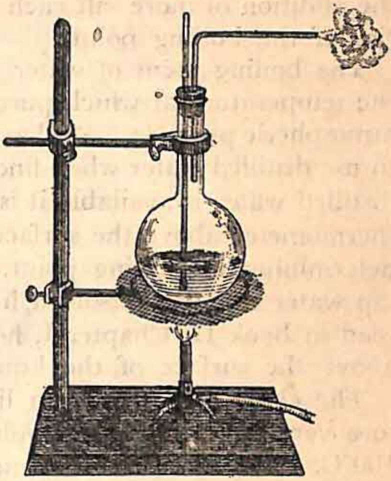


*The working parts of the household refrigerator.*

A practical way of applying this method in the case of a household refrigerator is shown in the accompanying diagram. In this case heat produced by the liquefaction in the condenser is removed by the air circulating along the fins fixed on the coils of the condenser, which greatly increases the area for cooling purposes.

**Boiling.** Boiling is the rapid conversion of a liquid to vapour at a temperature called the boiling point of the liquid. Unlike evaporation, the vapour is formed not at the surface of the liquid but throughout the body of the liquid.

Let us consider what happens when water is boiled. Fill a flask with distilled water which has been previously exposed to air and fit it with a two-holed stopper. Insert a thermometer through one hole of the stopper so that the bulb is immersed in the water. Through the other hole of the stopper insert a bent tube. Heat the water in the flask over a strong flame. Soon you will observe bubbles forming within the liquid and eventually rising to the surface. These are bubbles of air which were dissolved in the water but are expelled from the water when it is heated. The next sign to look for is a misty vapour forming on the surface of the water. The misty vapour is caused by a small amount of water evaporating from the surface, meeting the cool air in the flask and condensing to form a mist of tiny droplets of water. As the water continues to receive heat, more bubbles are formed within the liquid. These bubbles contain very hot water vapour called steam, which is formed inside the body of the liquid. But as the temperature rises, the pressure of the vapour within the bubbles becomes equal to the atmospheric pressure and the bubbles rise to the surface where they burst. Now the water is said to be boiling.



*The temperature at which water boils remains the same until all the water has changed to steam.*

While boiling is taking place the temperature remains the same, until the whole of the liquid has been converted to vapour. During the conversion of water to vapour the heat received is used to bring about a change of state.

The presence of dissolved substances in a liquid raises the boiling point of the liquid. Repeat the same experiment adding some salt to the water. You will find that the boiling point is raised. Further repetitions of the experiment with the addition of more salt each time, will result in a further rise of the boiling point.

The boiling point of water has already been defined as the temperature at which pure water boils under standard atmospheric pressure. We have just seen why it is necessary to use distilled water when finding its boiling point. Unless distilled water is available it is best to keep the bulb of the thermometer above the surface of water in the flask when determining its boiling point, for in most cases ordinary tap water contains dissolved impurities. We have already read in Book II, Chapter I, how alterations in the pressure above the surface of the liquid affects its boiling point.

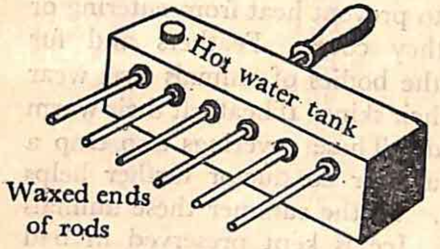
The change of state from liquid to vapour corresponds to a very large increase in volume, thus 1 c.c. of water at 100°C. changes into a little more than 600 c.c. of vapour.

Pure substances melt at certain fixed temperatures. Knowledge of the melting point and boiling point of a substance helps to identify it and also to test its purity.

**Conduction.** If you take a metal spoon in one hand and a wooden ruler in the other and plunge their ends into very hot water, you will soon drop the spoon. Heat travels along both the spoon and the ruler. At first the particles of each solid that are immersed in the hot water get hot, then these particles communicate heat to the neighbouring particles and in this way heat travels from particle to particle along the entire length of each solid. When heat is transmitted along a body from particle to particle, without any movement of the particles, the process is called conduction. Because heat travels along the spoon more readily than it does along the ruler, metal is said to be a good conductor of heat whereas wood is a bad conductor of heat. All metals are good conductors. Wool, stone, glass, wood, porcelain, water and air are all bad conductors.

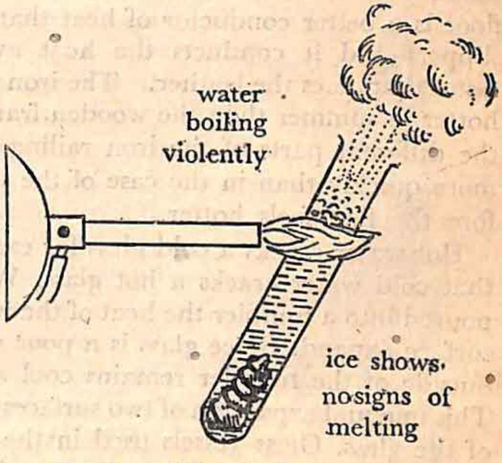
Take rods made of different materials belonging to

Ingenhousz's apparatus and coat each rod with wax. Introduce them into the holes of a rectangular box fitted with a handle as shown. Pour boiling water into the box. As the ends of the rods that are in contact with the boiling water get heated the heat is passed along their lengths and the wax on each melts. It will be found that the wax melts rapidly along certain rods and scarcely along others. The speed with which the wax melts along a particular rod indicates its conductivity with respect to the others.



*Ingenhousz's apparatus.*

Load a piece of ice by wrapping a piece of wire around it and put it into a test-tube. Fill three-fourths of the test-tube with water. Now hold the test-tube at an incline and heat the surface of the water with a bunsen flame as shown. You will find that the ice does not melt. Although the water at the surface begins to boil, yet because it is a bad conductor of heat, very little of the heat at the surface is transmitted to the ice.



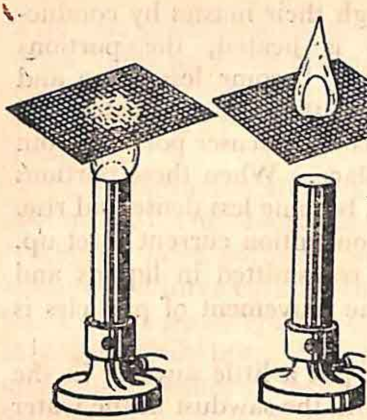
*To show that water is a poor conductor of heat.*

In the kitchen we use vessels made of metal to boil water. The heat from the stove is conducted easily through the metal and soon boils the water. On the other hand, hot liquids are drunk from vessels made of bad conducting materials such as porcelain and earthenware.

Poor conductors are used to keep hot things hot and cold things cold. They are able to prevent heat from entering or escaping from whatever they cover. Feathers and fur prevent heat from leaving the bodies of animals that wear these poor conductors over their skins. If heat left their warm bodies they would feel cold. These coverings also trap a layer of air which being a poor conductor further helps to keep their bodies warm. In the summer these animals shed much of their coats. Ice is kept preserved in bad conductors such as sawdust or in a piece of flannel or blanket.

When you step out of bed in the morning you put your feet into slippers. If you were to walk on the floor without them, your feet would feel cold. This is because the stone floor is a better conductor of heat than the leather of your slippers and it conducts the heat away from your feet faster than does the leather. The iron railings of a gate feel hotter in summer than the wooden framework. Heat from the different parts of the iron railing passes to your hand more quickly than in the case of the woodwork and therefore the first feels hotter.

Hot water cracks a cold glass for exactly the same reason that cold water cracks a hot glass. When boiling water is poured into a tumbler the heat of the water makes the inside surface expand. Since glass is a poor conductor of heat the outside of the tumbler remains cool and does not expand. This unequal expansion of two surfaces results in the cracking of the glass. Glass vessels used in the laboratory are made with very thin walls. Heat passes rapidly through the walls and throughout the entire vessel. Unequal expansion of

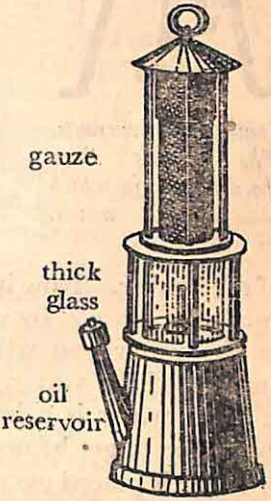


*To show the action of a wire gauze on a bunsen flame.*

any part of the surface is thus avoided.

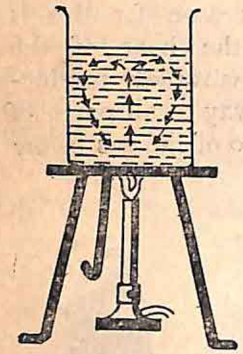
Place a wire gauze over a bunsen flame and open the tap of the burner. The gas leaving the nozzle of the burner flows through the gauze. Light the gas that is above the gauze. Notice that the gas below the gauze does not burn. The reason for this is that the heat of the flame is rapidly conducted away to all parts of the gauze and as a result the temperature of the gas below the gauze does not rise sufficiently for combustion to take place.

Davy's safety lamp used by miners is an application of the principle tested in the above experiment. The lamp consists of an ordinary oil lamp surrounded by a wire gauze. Owing to the conducting power of the gauze the heat of the flame is conducted away rapidly and so the temperature outside the lamp is never high enough to bring about the combustion of any explosive gases that may be present in the mine. Such gases as pass through the gauze into the lamp are burnt within.



*Davy's safety lamp.*

**Convection.** Liquids and gases are bad conductors of heat and so heat is hardly transmitted through their masses by conduction. When a liquid or gas is heated, the portions nearest the source of heat expands, become less dense and rises. The particles in the portions that rise are heated and take their heat with them. The colder, denser portions from above now fall and take their place. When these portions in turn are heated, they expand, become less dense and rise. In this way a current called a convention current is set up. This process by which heat is transmitted in liquids and gases from place to place by the movement of particles is called convention.



*Convection currents. The arrows show the direction in which the sawdust moves.*

Fill a beaker with water and put a little sawdust in the water. Mix the sawdust in the water with a glass rod so as to distribute it uniformily in the water. Place the beaker on a tripod stand as shown and heat it with a bunsen flame. As the water above the flame is heated, it expands, becomes less dese and rises. Cold water from the sides of the beaker takes the place of the water that has risen. The water that rises, on reaching the surface cools, contracts and, being denser than the water that is pushing up from below, is forced sideways. It moves in the only direction possible, that is, downwards, along the sides of the beaker. Now it meets the heat of the flame again and rises once more. By watching the movement of the sawdust in the water you will be able to observe the convection current of the water.

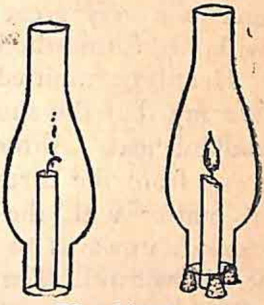
Since water is a bad conductor of heat it should take a long time to get heated; yet this is not so. When a saucepan of water is placed over a stove the heat of the stove is carried from one place to another by convection currents, and the water boils in a few minutes.

Let us turn our attention to gases and see what heat does to them. We will experiment with air as it is easily available.

Place a lighted candle on the table and put a glass chimney around it. The flame soon goes out.

Repeat this experiment with a slight change. Place the chimney on three corks so that it is well off the table. The flame now burns brightly. The air above the flame continues to be expelled, but now a supply of fresh cool air rushes under the chimney to take its place.

Set fire to a piece of paper, and then blow it out so that it makes some smoke. Hold the paper below the chimney and note the direction taken by the smoke. In this way you will be able to follow the direction of the moving air that flows around the burning candle.


*The chimney experiment.*

There is always need for a continuous flow of fresh air into a room and a way of removing the impure air, or in other words, for ventilation. Fresh air brings a supply of oxygen which we use to breathe. The air we breathe in is warmed in our bodies and the warm air we breathe out contains more carbon dioxide and water vapour than it did before. This warm moist air is pushed up towards the ceiling by the cooler, heavier air that flows in to take its place. If there is no way for the expired air to escape, the air in the room would become warmed and moistened. This would make the room feel 'stuffy'. Lassitude, fatigue, headache and poor health are the results of living in stuffy rooms. To prevent stuffiness, windows called ventilators are built at the top of the room to allow expired air to escape. A fan or some other means by which the air in the room is kept circulating also helps stuffiness to disappear.

Trade winds and land and sea breezes of which you read in Book I together with ocean currents are the effects of convection currents in air and water that occur in nature on a vast scale.

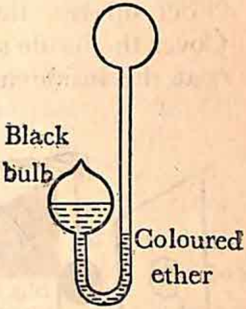
**Radiation.** In conduction and convection, heat is transmitted by the aid of particles of matter. In the third mode of heat transmission, called radiation, heat is transmitted from one body to another in straight lines, in all directions and at a very great speed without the aid of matter and without heating the medium through which it passes.

Heat is transmitted from the sun to the earth by radiation. We say that the sun radiates heat and this heat is called radiant heat. Although the sun is about 92½ million miles away from the earth and the intervening space is devoid of matter with the exception of the atmosphere which extends upwards to about 200 miles, yet we are able to feel its warmth. The intervening space and the atmosphere allow heat to pass through without absorbing much heat and hence their temperatures are not much affected. When heat falls on the earth, however, it is absorbed and consequently the temperature of the earth rises. Thereafter, the earth radiates the heat which it has absorbed.

The heat from a fire reaches us by radiation. If we hold a thermometer below a flame we will note that the temperature rises. The heat could not have reached the bulb of the thermometer by conduction, as air is a poor conductor of heat; nor could it have reached the bulb by convection, as convection currents would carry the heat upwards; it is evident therefore that the bulb has become heated by radiation.

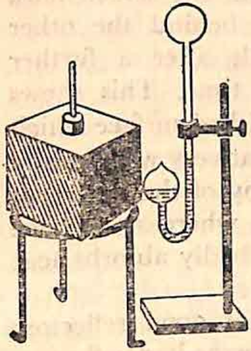
If you place a screen before a fireplace and stand on the side of the screen that is away from the fire, you will find that you do not feel the heat from the fire. This is because the screen has stopped the heat radiated from the fire from reaching you.

When we perform experiments on radiation we find that a mercury thermometer is not sensitive enough to record changes in temperature. We therefore use an instrument called an ether thermoscope. It consists of a *J*-tube with a bulb at either end of the *J*, the lower bulb and part of the tube being filled with ether to which a little colouring matter has been added. There is no air in the instrument and the space above the ether is filled with ether vapour. When heat radiations fall on the lower bulb they are absorbed, the ether and the ether vapour in this bulb expand and this produces a rise of the ether level in the other longer tube. By judging the rise in the ether column for various heat radiations we can obtain a rough measure of the amount of radiation which falls on the bulb.



*A Thermoscope.*

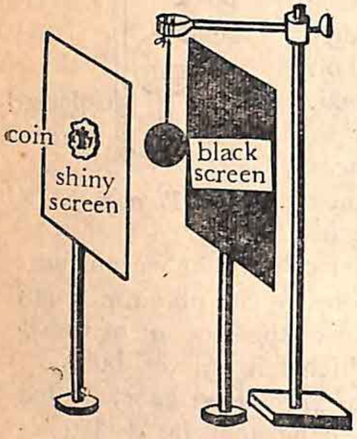
A large hollow cube, called Leslie's cube, may be used together with the ether thermoscope to compare the radiating powers of various surfaces. One of the faces of the cube is highly polished, the second painted white, the third varnished and the fourth coated with lampblack. Pour boiling water into the cube through the opening at the top. Place the ether thermoscope a distance of 5 inches from each face of the cube



*Apparatus used to compare the radiating powers of various surfaces.*

in turn. Note how high the ether column rises in each case during a period of two minutes. To make sure that your results are accurate you must see that the temperature of the water is the same for each recording. A thermometer fitted in the stopper of the cube will help you to do this. You will find that the radiating power of a dull surface is greater than that of a polished surface.

Set up two tin screens so that they face each other. Cover the inside surface of one screen with silver paper and coat the inside surface of the other with lampblack. Fix a 10 paisa coin by means of wax at the back of each screen. Heat a small iron ball until it is red-hot and then interpose it between the screen so that it is at the same distance from each of them. You will find that lampblack absorbs heat quickly and the heat absorbed melts the wax so that the coin behind the screen falls. The coin behind the other screen falls after a further length of time. This shows that a polished surface which reflects heat very well, hardly absorbs any of the heat that falls on it, whereas a surface such as lampblack which reflects heat badly absorbs heat very well.



*How to compare the absorption of radiant heat by black and shiny surfaces.*

The above two experiments show that good reflectors are bad absorbers and bad radiators, whereas bad reflectors are good absorbers and good radiators. These facts have received several applications in daily life.

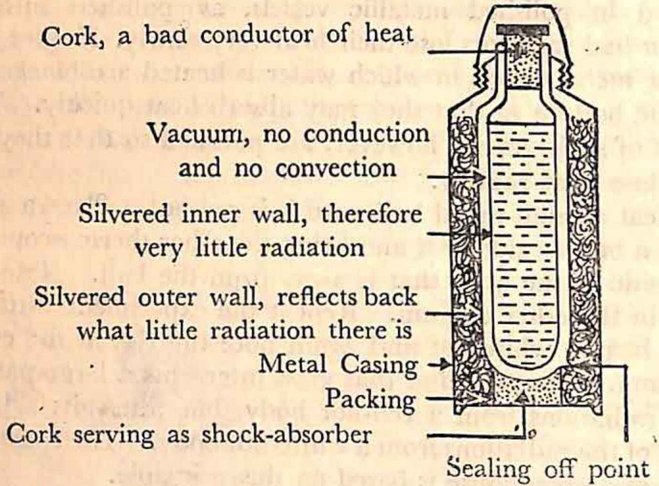
In summer, people wear white clothes so that the heat from the sun may be reflected and their bodies may not become heated. Liquids that are to be kept warm are stored in polished metallic vessels, as polished surfaces being bad radiators lose their heat very slowly. Kettles and other metal vessels in which water is heated are blackened at the bottom so that they may absorb heat quickly. The sides of such vessels, however, are polished so that they do not lose heat rapidly.

Heat a small metal ball until it is red-hot. Place a glass screen on one side of it and bring the ether thermoscope on the side of the glass that is away from the ball. Note the rise in the ether column. Repeat the experiment with the ball heated white-hot and again note the rise in the ether column. You will find that glass intercepts a large part of the radiations from a red-hot body, but transmits a large part of the radiations from a white-hot body. The construction of a greenhouse is based on this principle.

The glass walls of the greenhouse allow radiant heat from the sun to pass through, the white-hot surface of the sun being about 6,000°C. The radiations passing into the greenhouse are used by the plants inside. Since their temperature, however, is always well below 100°C., little of the heat radiated by them and from the ground and walls can pass through the glass and so most of it remains in the greenhouse. On cold nights the plants inside the greenhouse are warmed by hot-water pipes and since the temperature of the water flowing in the pipes is also below 100°C. hardly any heat passes out of the greenhouse by radiation.

**The Thermos Flask.** This flask is used to keep hot liquids hot and cold liquids cold. It is constructed so that heat lost or heat gained by the flask by conduction, convection and radiation is reduced to a minimum.

The flask consists of a double-walled vessel of thin glass with the inner surfaces of the walls silvered. Air is pumped out of the space between the walls and the opening through which this is done is sealed.


Cork, a bad conductor of heat
Vacuum, no conduction and no convection
Silvered inner wall, therefore very little radiation
Silvered outer wall, reflects back what little radiation there is
Metal Casing
Packing
Cork serving as shock-absorber
Sealing off point

*The vacuum flask.*

Heat lost or gained by conduction is reduced to a minimum because it would have to pass through the glass first and glass as you know is a bad conductor of heat. If heat did pass through the glass it would reach the vacuum and as conduction requires a medium, the passage of the heat into or from the flask would cease. A very small amount of heat passes by conduction through the top of the glass walls of the flask.

Heat lost or gained by convection currents is minimised by the stopper which limits convection currents to the small air space above the liquid.

Finally radiation is reduced to a minimum by the silvered surfaces. If heat from a hot liquid in the flask passes through the inner walls of the flask by conduction it would pass through the vacuum by radiation. The inner walls, however, would not only radiate a small amount of heat being silvered, but also reflect heat radiations to and fro in the vacuum and thus prevent heat from leaving the flask. If the flask, on the other hand, contains a cold liquid, the small amount of heat from the outside, conducted through the outer glass walls would also be reflected to and fro in the vacuum by the silvered surfaces and thus be prevented from passing through the inner walls of the flask.

## CHAPTER ACTIVITIES

### *Outdoors*

Look out for these examples of how heat affects the common things around you.

(*a*) Small spaces are left between sections of railway lines. On a hot summer's day the rails expand and come close together at their ends. It is the space between them that prevents the rails from buckling.

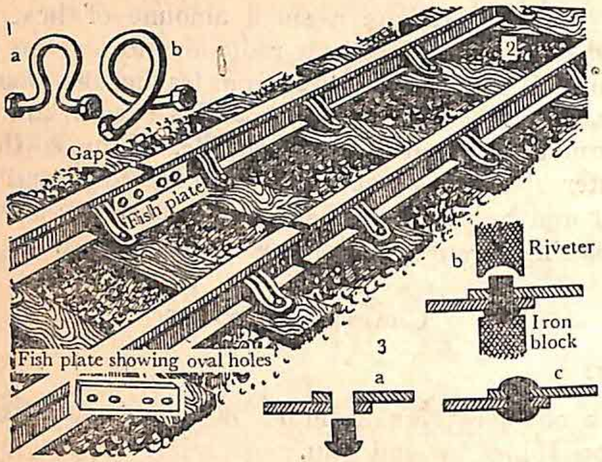
(*b*) Telegraph wires hang loosely in the hot weather but are taut in winter.

(*c*) When houses are built, in the case of large terraced roofs expansion joints are provided so that the expansion of the roof terrace in the summer months may not result in permanent damage to the building.

(*d*) The ends of each span of an iron bridge are not rigidly fixed to their supports, but placed on rollers so as to allow for expansion and contraction in the hot and cold seasons.

(*e*) Metal pipes used to carry gas, steam or hot water are looped at intervals, These loops are able to take up any expansion in the straight portions of the pipe when they undergo high changes of temperature.

(*f*) When two metal plates are rivetted together, they are first made to overlap so that the holes drilled in them come together, then metal rivets that have



*1(a) and (b). Expansion loops in steam pipes.*
*2. How railway lines are laid to allow for expansion.*
*3. (a), (b) and (c) Stages in riveting.*

been strongly heated are pushed through the holes and hammered flat from both sides. As the rivets cool they contract and pull the plates firmly together.

2. In certain public places you will see thermometers which contain a pink liquid. Write a description of such a thermometer.

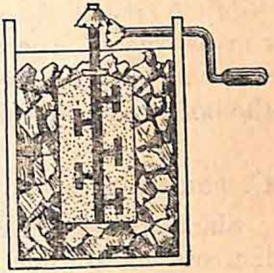
3. Look out for these practical applications of the facts relating to change of state.

A. MELTING POINT :

(*a*) A domestic ice-cream making machine has its inner compartment surrounded by a freezing mixture. The ingredients for the making of ice-cream are placed in the inner compartment and then churned. When the temperature of the ingredients drops below 0°C. they freeze.

(*b*) Many different kinds of foodstuffs are preserved in a freezing mixture.

(*c*) If you spend the winter at a hill station you will notice that when a rickshaw passes over a snow-covered road the increased pressure lowers the melting point of snow from 0°C. to just a little less. Consequently some of the snow melts. Once the rickshaw has passed on its way and the pressure is removed the melted snow freezes to ice.


*Ice-cream making machine.*

(*d*) A snowball is made by pressing snow between the hands. The pressure of the hands lowers the melting point of the snow and some of it melts. When the pressure on the snow is released the water formed freezes, binding the snowball together. If the temperature is far below 0°C. the pressure of the hands is insufficient to melt the snow. Snowballs can only be made with snow which is a few degrees below the melting point.

B. EVAPORATION :

(*a*) During the dry hot summer months water used for drinking purposes is stored in porous earthen pitchers. Water continually oozes out of the sides of the pitcher and evaporates. This results in heat being carried away from the pitcher and the consequent cooling of water in the pitcher.

(*b*) We perspire more in summer than in winter. As the perspiration comes out on to our skin it evaporates and removes heat from our bodies, thereby producing a sensation of cold.

(*c*) Wet khus-khus screens are hung near doors and windows during the hot weather. Water is sprinkled on these screens from time to time. The evaporation of water takes away the heat from the air in the room thus causing a cooling effect.

(*d*) A metal water bottle is usually covered with a canvas cover. The cover is continually kept wet. As the water evaporates from the cover, heat is absorbed from the bottle and the water in the bottle becomes cold.

### C. BOILING POINT :

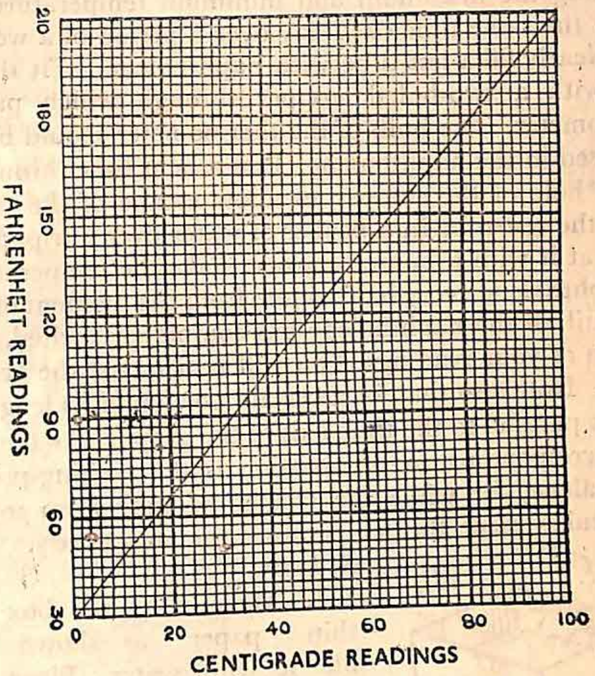
Since the boiling point of water drops with the increase in altitude (and the corresponding decrease in pressure) food does not cook properly at the tops of high mountains. Reference has already been made to a pressure cooker in Book II, Chapter I.

### *For your wall newspaper*

The conversion of temperatures from one scale to another becomes an easy matter once you have prepared a graph which compares the two scales.

Fill some water in a beaker and heat it near to boiling point. Allow the water to cool. Stir the water as it cools and read its temperature using both Centigrade and Fahrenheit thermometers. Add a little cold water, stir well and read the thermometers as before. Repeat this process, until you have obtained twelve pairs of readings. Plot the points for corresponding readings on a sheet of graph paper as shown.

To convert a Fahrenheit temperature to the corresponding Centigrade temperature draw a horizontal line through the given reading on the Fahrenheit axis, and a vertical line through the point where this line cuts the graph. The point where the vertical line cuts the Centigrade axis gives the corresponding reading on the Centigrade scale. Reverse the above procedure to convert Centigrade temperatures to Fahrenheit temperatures.



*A graph which will help you to convert temperatures from one scale to the other.*

*Note-book exercise*

Prepare a report showing how the various facts given in this chapter have received practical applications in your home.

*Laboratory work*

1. Secure a Centigrade thermometer and a Fahrenheit thermometer. Test the accuracy of their graduations by

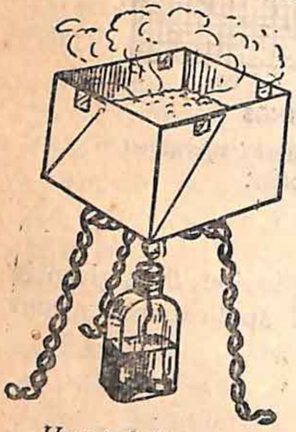
placing each in turn in melting ice and steam as outlined on pages 128 and 129.

2. Learn to use the maximum and minimum thermometer by taking the maximum and minimum temperature readings at the same time each day over a period of a week.

3. Nearly fill a test-tube with naphthalene. Fit the test-tube with a two-holed stopper through which passes a thermometer. The bulb of the thermometer should be well immersed in the naphthalene. Pass a bent tube through the second hole of the stopper to allow escape of the vapour. Stand the test-tube in a beaker of water over a tripod stand and heat it with a bunsen burner. Take the temperature of the naphthalene every half minute from the moment of heating, until all the naphthalene has completely melted. Draw a graph of your readings. You will notice that the graph is curved. Note also that for a certain portion of its length the curve is parallel to the time axis of the graph. The temperature corresponding to this portion is the melting-point of naphthalene, for while the change of state from solid to liquid takes place the temperature remains steady.

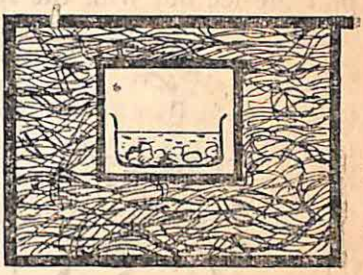
*At home*

1. Make a paper box with thin paper as shown and fill it with water. Place it on a tripod stand and heat it with a spirit lamp. You will find that although the water boils, the paper is not charred. This is because the heat from the flame is conducted through the paper very quickly and then rapidly carried away by convection so that the temperature of the paper is never allowed to reach a sufficient temperature for it to burn.



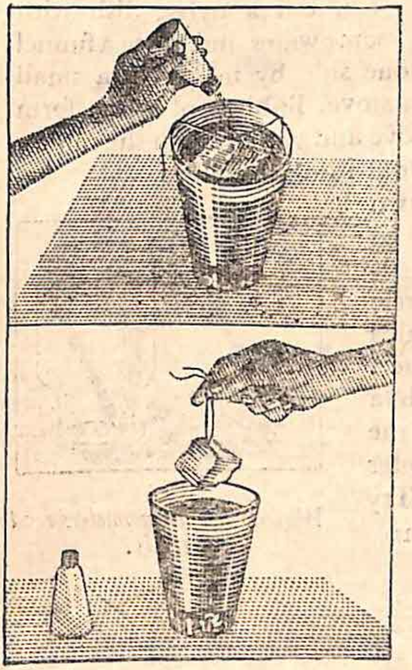
*How to boil water in a paper vessel.*

2. Make a straw-box to keep foodstuffs at a constant temperature. It consists of two wooden boxes, one inside the other. The space between the two boxes is filled with straw. The straw is a poor conductor of heat and so does not allow heat to enter or to excape from the inner box.



*A straw-box.*

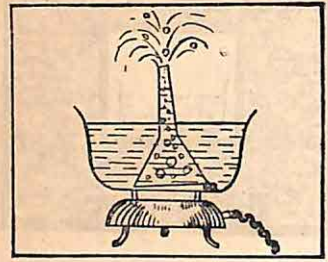
3. Close all the windows of a room in your house leaving only the door open. Hold a lighted candle at different positions in the opening of the doorway and observe which way the flame turns. The flame points out to you the directions of the air currents entering and leaving the room.



*How to remove an ice cube from a tumbler full of water by means of a string.*

4. With the help of some salt and a length of string you can lift a piece of ice out of a tumbler full of water. Wet one end of the string and lay it on top of the ice. Sprinkle some salt on each side of the string and on the part of the

string which is on the ice. After a few moments gently pull the ice out with the string. Explain the result.

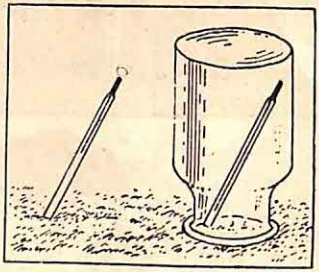


*A home-made geyser.*

5. Pour a teaspoonful each of scent, glue, alcohol, ether, coconut oil, petrol, water and turpentine into separate saucers. Find out which liquid evaporates first. Make a list of these liquids in the order of the speed in which they evaporate.

6. Fill a pyrex dish with some water and place a funnel in it. Raise the funnel on one side by means of a small stone. Heat the water over a stove. Bubbles of steam form in the water, just above the stove and gathering in the mouth of the funnel force the water out into the stem.

7. You will require two thermometers and a jam-jar to study the action of a greenhouse. Stick both thermometers in the soil with their bulbs projecting above the surface. Cover the bulb of one with a jam-jar as shown. Note the reading of each thermometer hourly on a sunny day. Try to account for the difference in readings.



*Why do the thermometers read differently?*

## CHAPTER V

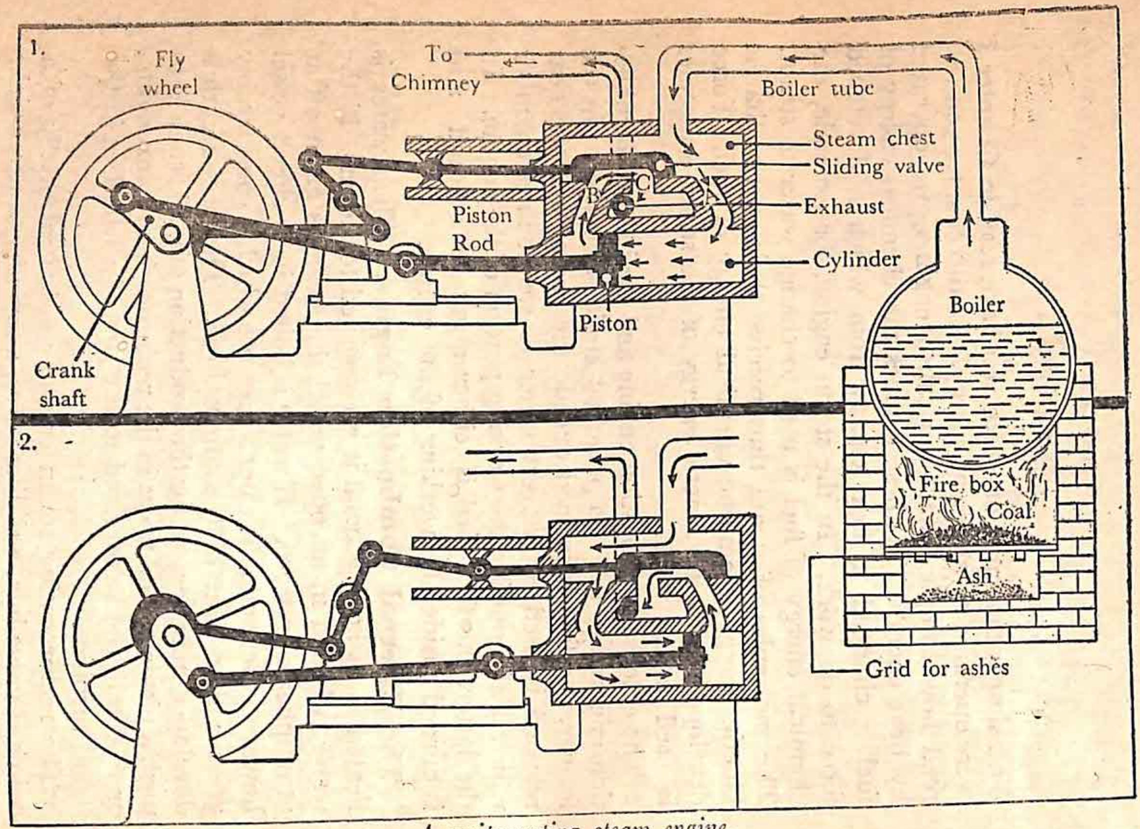
## ENGINES

THE simple machines of which you have read in Chapter I were operated by muscular energy. In this chapter you will read how complex machines called engines, are operated by heat energy. In these engines the chemical energy of fuel is changed to heat energy from which is developed force to do work. In the steam engine, for example, the chemical energy of fuel is used to change water to steam. The molecules of steam thus receive their energy that is kinetic energy, from the chemical energy of fuel. Force developed from the kinetic energy of the steam molecules is used to do work.

The external combustion engine and the internal combustion engine are the two principal kinds of engines. In the former, the fuel is burned outside the engine and the heat released is used to convert water to steam in a chamber which is also outside the working portion of the engine. In the latter, the fuel used is either a gas or a liquid and is burned inside the working of the engine.

**The External Combustion Engine.** When water is heated to its boiling point it is converted to steam. If the water is boiled in an open vessel the steam is given off at atmospheric pressure. If water is boiled in a closed vessel however, the steam develops a pressure which is considerably greater than that of the atmosphere. The pressure thus developed may be used for the production of work, such as to push a piston to and fro as in the reciprocating steam engine, or to rotate the vanes fixed to the rim of a wheel as in the steam turbine.

The reciprocating steam engine consists essentially of a boiler, a valve box, a sliding valve, a cylinder, a steam-tight piston, a crank shaft, a flywheel and connection rods.



*A reciprocating steam engine.*

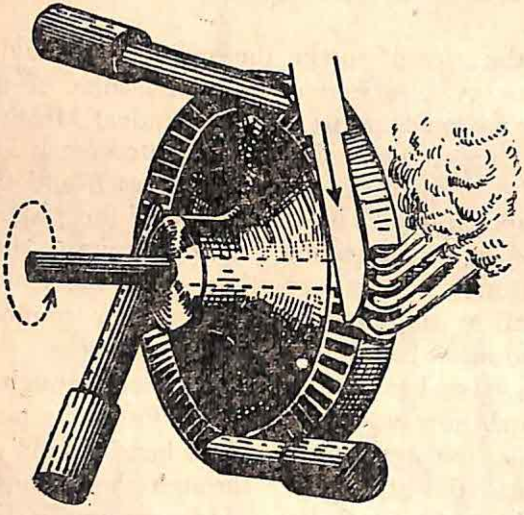
1. *Steam entering the right hand side of the piston.* 2. *Steam entering the left hand side of the piston.* *A, B, and C, openings. The arrows show the path taken by the steam.*

The boiler is connected by a tube to the valve box. Steam from the boiler enters the valve box and thereafter enters the cylinder by either the opening marked *A* or the one marked *B* in the diagram. The supply of steam through these alternate openings is regulated by a sliding valve which is drawn to and fro by a connecting rod so that steam is first admitted on one side of the piston and then on the other. A third opening marked *C* provides communication between the exhaust and the cylinder by way of either *A* or *B* depending on the position of the sliding valve.

When the steam enters the cylinder through *A*, the kinetic energy possessed by the molecules of the steam forces the piston forward in the cylinder. Meanwhile, the steam on the left hand side of the piston escapes into the atmosphere through the exhaust pipe as *B* and *C* are now in communication. The movement of the piston is communicated by a connecting rod to the crank shaft which moves through half a revolution. The movement of the crank shaft is communicated by another connecting rod to the sliding valve which has now moved so that steam from the valve box enters the cylinder through *B*. The steam which now enters the cylinder forces the piston back. Meanwhile, the steam on the right hand side of the piston escapes into the atmosphere through the exhaust pipe as the openings *A* and *C* are now in communication. The movement of the piston is again communicated by the connecting rod to the crank shaft which moves through another half revolution. In this way one complete revolution of the crank shaft is produced. The crank shaft is attached to the axle of a flywheel. A large flywheel by its great inertia enables the crank shaft to move freely and smoothly. The back and forth motion of the piston is changed to a rotary motion of the flywheel by the crank shaft.

The reciprocating steam engine is used in railway trains, in electric power stations and in operating certain machines in factories.

The steam turbine has gradually displaced the reciprocating steam engine especially in ocean liners and in electric power stations. It is an application of the wheel and axle. The wheel consists entirely of vanes fitted side by side to each other while the axle is fixed to a shaft. Steam is directed against the vanes by suitably placed nozzles and its kinetic energy forces the turbine to rotate at a considerable speed.



*A steam turbine.*
*Jets of steam from the nozzles turn the vanes of the turbine which revolve the shaft in the direction of the dotted arrow.*

The movement of the turbine is communicated to an engine by the shaft which runs through its axis.

**The Internal Combustion Engine.** In this engine the fuel is burned inside the cylinder. Here the heat of combustion is used directly to bring about work without the use of steam. When the fuels are burned, the heat expands the gases and the resulting pressure exerted by the gases drives the piston with a reciprocating motion which is changed by a crank shaft into a rotary motion used to operate the machinery and to do work.

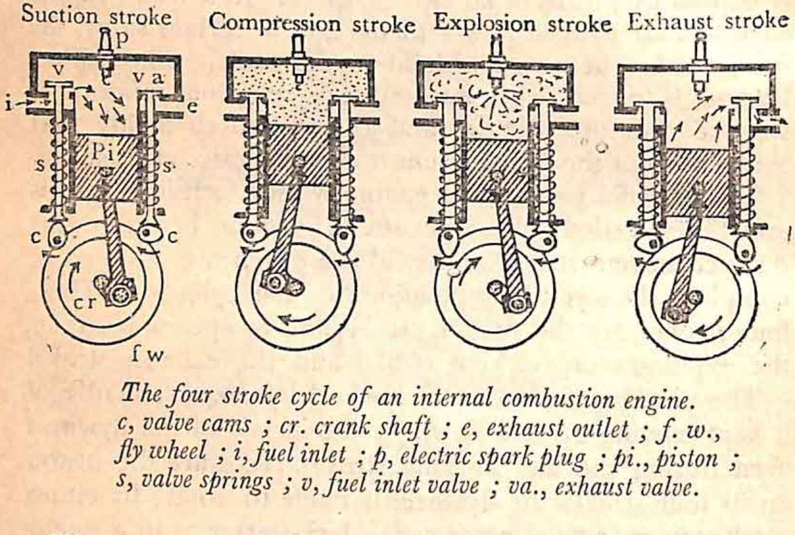
The fuels used may be a gas such as coal-gas or a liquid which is easily vaporised such as petrol, alcohol and benzene. The gas or the vapour of the liquid used is mixed with air and the resulting mixture is explosive. In the case of a petrol engine such as that of a motor car the gaseous mixture is ignited by means of an electric spark. In a diesel engine such as that used in power plants and in certain ships, the fuel used is a heavy oil which liquefies easily. The vapour formed is mixed with air and the resulting mixture is sprayed into the cylinder and compressed so highly that the heat from the compression makes the gases explode.

The internal combustion engine we will consider here is sometimes called the four stroke engine because four distinct movements or strokes of the piston are required to complete the cycle of operations in the cylinder. These four strokes are the suction stroke, the compression stroke, the explosion or working stroke and the exhaust stroke.

The piston is fixed to the flywheel by a crank shaft and is kept moving up and down by the inertia of the flywheel even during the non-working strokes. To start the piston on its four strokes the flywheel is made to rotate by either a self-starter as in a motor car, a kick-starter as in a motor cycle or a propeller as in an aeroplane. The flywheel possesses great inertia on account of its heavy weight. Once it is set rotating its inertia changes from an inertia of rest to an inertia of motion, that is, it now has a tendency to go on rotating.

During the suction stroke the piston descends and a valve called the inlet valve opens the fuel inlet so that a mixture of gaseous fuel and air is drawn into the cylinder. Another valve called the exhaust valve keeps the exhaust outlet closed. The inlet and exhaust valves are kept closed by springs and opened by cams which are operated by the rotation of the flywheel.

The suction stroke is followed by the compression stroke during which the gases that have entered the cylinder are highly compressed due to the continued rotation of the flywheel which moves the piston upwards. Both valves remain closed throughout this stroke and the next.


Suction stroke Compression stroke Explosion stroke Exhaust stroke

*The four stroke cycle of an internal combustion engine. c, valve cams ; cr. crank shaft ; e, exhaust outlet ; f. w., fly wheel ; i, fuel inlet ; p, electric spark plug ; pi., piston ; s, valve springs ; v, fuel inlet valve ; va., exhaust valve.*

The compressed gases are ignited by a spark during the explosion stroke and being highly inflammable, explode. The heat of the explosion expands the gases and a very high pressure is developed in the cylinder. Consequently, the piston is forced downwards. The downward movement of the piston causes the flywheel to rotate until the next explosion stroke occurs. As the piston moves downwards the pressure inside the cylinder decreases while the volume increases.

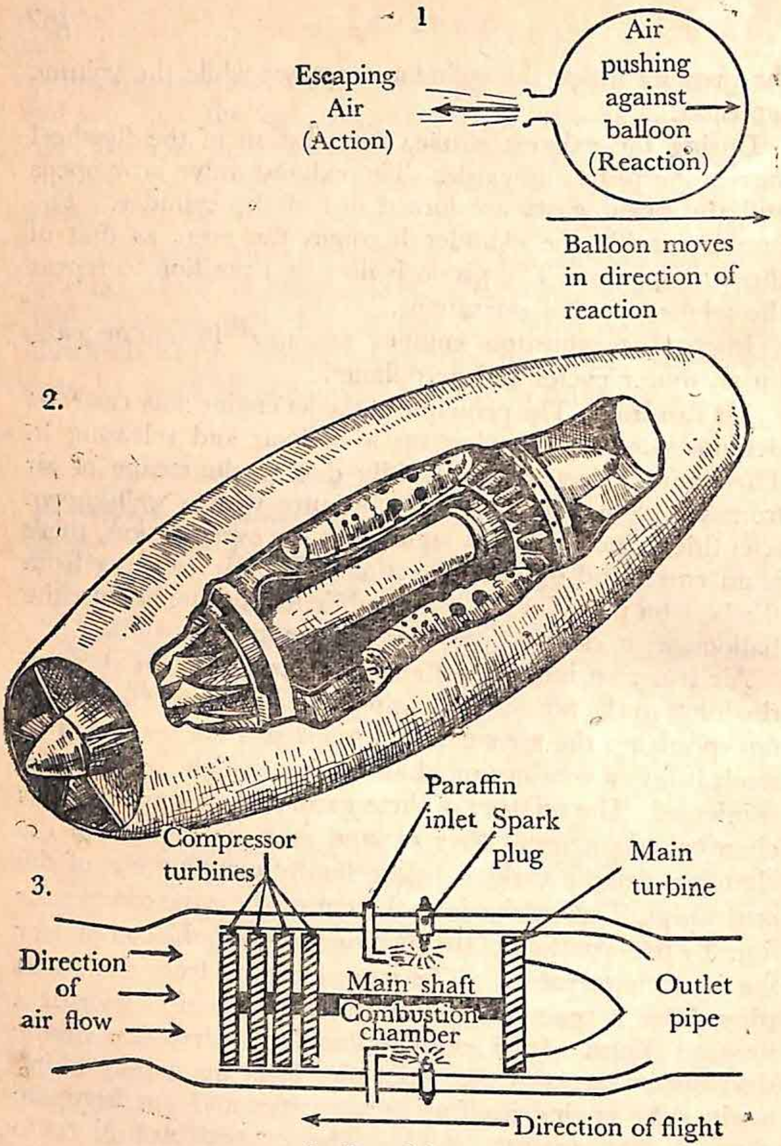
During the exhaust stroke, the rotation of the flywheel carries the piston upwards. The exhaust valve now opens and the burnt gases are forced out of the cylinder. The pressure inside the cylinder becomes the same as that of the atmosphere. The piston is now in a position to repeat the whole cycle of operations.

Internal combustion engines are used in motor cars, buses, motor cycles and aeroplanes.

**Jet Engines.** The principle of the jet engine may easily be demonstrated by blowing up a balloon and releasing it. The balloon darts away rapidly due to the escape of air from within it. This is in accordance with a well-known scientific principle which states that for every action, there is an equal and opposite reaction. The air escaping from the balloon provides the action while its pushing against the balloon as it escapes, provides the reaction.

Air is drawn into the jet engine of an aeroplane through the inlets in the nose of the engine by a compressor fan. This fan speeds up the air current, compresses the air and then sends it into a combustion chamber into which paraffin fuel is injected. The mixture of these gases is then ignited in this chamber. As a result they expand and rushing out of the chamber drive a turbine before finally escaping out of the outlet pipe. The turbine is on the same axle as the compressor fan. By the rotation of the turbine therefore, the compressor fan is made to rotate. The gases escaping from the outlet pipe cause a reaction against the engine which gives it a forward thrust. It is evident therefore, that the engine develops its thrust at the outlet pipe from the gases pushing against the engine itself as they escape, and not from the gases pushing against the air. The forward push given to the engine is equal to the push of the gases as they escape.

There are two chief kinds of jet engines : the turbo-jet



*Jet Propulsion.*
1. *How a balloon is pushed by escaping air.* 2. *A jet engine.*
3. *Section of a jet engine.*

engine used in aeroplanes and the rocket engine used in rockets. In the former the air entering from the front of the engine is used to burn the fuel and the waste gases are expelled out of the jet at a considerable speed. In the latter, the fuel does not require outside air to burn, as it carries its own oxygen supply. It is used in rockets designed to soar above the atmosphere.

## CHAPTER ACTIVITIES

*Outdoors*

Visit a locomotive shed, a motor car workshop and a motor cycle workshop. Try to learn something more about the engines of which you have read.

*For your wall newspaper*

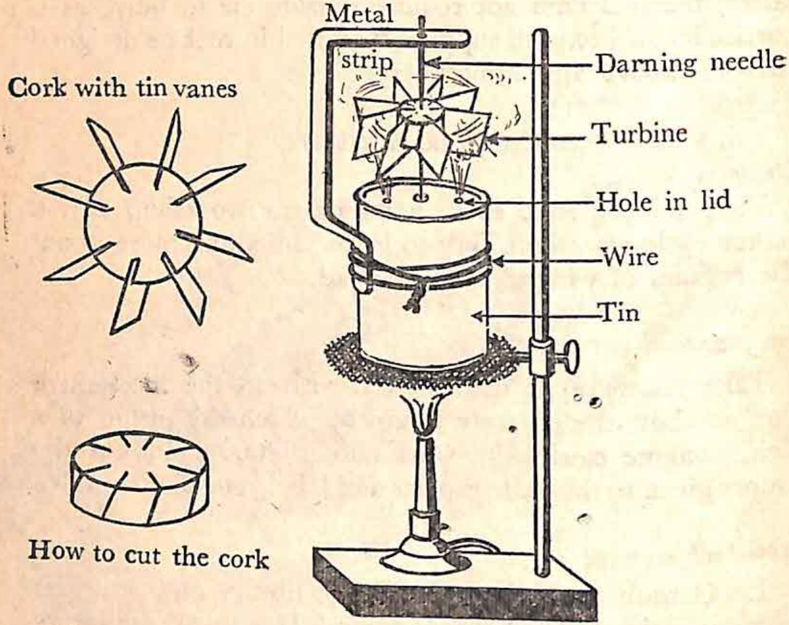
Take photographs during your visit to the locomotive shed to show the separate stages by which the piston of a steam engine causes the wheels to rotate. Find out the names given to the various parts and label your photographs.

*Note-book exercises*

1. Consult books in your science library and write an account entitled 'The Story of Steam'. Describe the pioneering efforts of the men who worked with steam and trace the history of the development of the first steam engine.
2. Write a summary of this chapter.

*At home*

You can make a model turbine by fitting a tin with a vane. Make a dent in the centre of the lid of the tin and punch two holes in the lid on either side and at equal distances from the dent. To make the vane, cut a cork obliquely round its edge as shown and pass a darning needle through its centre. Fit pieces of tin into the slits made in the cork to fix the vane. Take a strip of tin and punch a hole at its centre. Bend the strip and pass the darning needle through the hole in it. Adjust the strip over the tin so that the bottom



Cork with tin vanes

How to cut the cork

*A model turbine.*

end of the needle fits into the dent. Now bind the strip to the sides of the tin with wire.

When water is boiled in the tin, steam issues from the two openings and strikes the vane causing it to revolve rapidly.

## CHAPTER VI

## ACIDS, BASES AND SALTS

CHEMISTS divide all material substances into elements and compounds. Elements are substances which cannot be split into two or more simpler substances different from each other, such as hydrogen, oxygen, mercury, iron and so on. A compound is a substance which by suitable means can be split up into two or more simpler substances, different from each other, such as water which can be split up into hydrogen and oxygen.

A compound is to be distinguished from a mixture in which two or more different substances exist side by side being mixed even very intimately. To separate the constituents of a mixture from each other, there is no need of splitting the mixture but only to separate its constituents. An example of a mixture would be iron and sand in powder form, or water and oil well stirred together, and so on.

It is the special work of chemists to study the composition of compound substances and the changes in the composition that may be effected by various means. Therefore, chemists study the various substances found in nature, whether living or non-living things, in order to find the composition of each of them. As the result of an enormous number of experiments to analyse chemically as many as possible of the substances found in nature, it was found that in nature there exist 103 elements which cannot be further split up into simpler constituents dissimilar from each other. The hundreds of thousands of different substances found in nature consist of one or two or more of these 92 elements in different proportions joined together in a very compact and strong manner. It was the work of the chemists to find for each substance the number of different elements of which it was composed and the proportions of each of these elements, and also the way in which these different elements were joined together to form a particular substance having definite properties. This work has been going on for a long time, and naturally an enormous amount of information has been accumulated in this manner. Long ago it was evident to the scientists that they should try to put some order into all the accumulated data and so they began to compare and find similarities amongst the various data. It was towards the end of the nineteenth century some general rules were framed which were verified by all the chemical analyses performed up to then. It was found that to form a particular substance, two or more elements had to be combined together in definite proportions by weight. A few examples will make this clear. Thus, 2 gm. of hydrogen and 16 gm. of oxygen are to be combined to form 18 gm. of water; 2 gm. of hydrogen and 71 gm. of chlorine will form hydrochloric acid; 4 gm. of hydrogen and 12 gm. of carbon will form methane; 12 gm. of carbon and 32 gm. of oxygen will form carbon dioxide. In all these cases no residue of the component elements is left.

Considering further the above examples we see that they are interrelated, thus, 1 gm. of hydrogen combines with 8 gm. of oxygen or 35·5 gm. of chlorine or 3 gm. of carbon; and 8 gm. of oxygen combine with 3 gm. of carbon or 1 gm. of hydrogen and so on.

If instead of considering the weights of the elements to be combined we consider their volumes when they are in the gaseous state, then, once again it is found that elements combine in definite proportions by volume. Thus, 2 volumes of hydrogen combine with 1 volume of oxygen to produce 2 volumes of water vapour, 1 volume of hydrogen and 1 volume of chlorine combine to produce 2 volumes of hydrochloric acid.

Scientists have succeeded in framing some general laws summarising all the findings about these combinations in definite proportions by weight or volume. Upon these laws, an English chemist named John Dalton, in 1804, built his Atomic Theory which was to give a clear and satisfactory explanation about the way the various elements combine to constitute the different substances. His theory was further developed by an Italian physicist named Amedeo Avogadro, in 1811. This theory proved very useful for further investigation, in particular for the production of new substances by combining various elements in conformity with the principles of this Atomic Theory.

**Atoms and Molecules.** According to the atomic theory all material substances consist of very small particles, called molecules. These are the smallest particles into which a given substance can be divided without losing its special properties. Thus, water can be divided into even smaller parts until a part is reached, which, if divided further, would no longer be water. These molecules are kept together by forces of cohesion and the intensity of these forces for a given temperature and pressure will determine whether the substance is in the solid, liquid or gaseous state.

These molecules themselves may be split up into parts, by various means such as heat, pressure, electricity, and these parts, which have properties different from the molecule, if they cannot be further divided, are called atoms. Naturally, the number of different atoms is the same as the number of different elements. There exists 103 different atoms in nature out of which all the different molecules are formed.

The different atoms have naturally different properties, in particular, they have different weights or masses, and have different combining properties with regard to the other atoms. The atomic weights of the different atoms are given as a series of numbers, indicating the proportionate weights of the atoms. Thus, the atomic weights of hydrogen. carbon, oxygen, chlorine, iron and silver are respectively, 1, 12, 16, 35·5, 55·8, 107·8 which means that a carbon atom weighs 12 times more than a hydrogen atom and so on. Of course, it does not mean that a hydrogen atom weighs 1 gm. or a carbon atom weighs 12 gm.; in fact, it takes 300,000 million million million atoms of hydrogen to make up 1 gm. The size of these atoms is also exceedingly small : 250 million hydrogen atoms in a line make one inch, even the heaviest atom, that of uranium has a size only 2½ times that of hydrogen.

**Valency.** An important property of each atom is its facility of combining with other atoms to produce various molecules. Each atom has definite powers of combination with a certain number of other atoms, it may be able to combine with one only, or with more than one. We first take the example of hydrogen : one atom of oxygen can combine with two atoms of hydrogen to form a molecule of water ($H_2O$); one atom of chlorine combines with one atom of hydrogen, to give one molecule of hydrochloric acid ($HCl$); one atom of sulphur combines with two atoms of hydrogen to give one molecule of sulphuretted hydrogen ($H_2S$); one atom of nitrogen combines with three atoms of hydrogen to give one molecule of ammonia ($NH_3$). Hence we say that the combining power of oxygen, chlorine, sulphur, nitrogen with hydrogen are respectively 2, 1, 2, 3. If we now consider the combining powers of oxygen with different atoms, we find that the molecules of oxides of zinc, carbon (dioxide), magnesium, are obtained by combining one atom of oxygen with one of zinc ($ZnO$), by combining two oxygen atoms with one of carbon ($CO_2$), one magnesium atom with one oxygen atom ($MgO$) and so on. Once again this appears to be rather complicated, but order was once more established, and a final list of all the different atoms (elements) has been drawn up giving their symbols (the first one or two letters of their name) their atomic weights and their valencies.

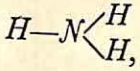
The valency of an atom is its combining power with a hydrogen atom or its equivalent. Thus, from the above examples we see that the valency of chlorine is 1, of oxygen is 2, of carbon is 4, because carbon can combine with two oxygen atoms, and each of these can combine with two hydrogen atoms, and so on.

## SOME OF THE MORE COMMON ELEMENTS

| *Name* | *Symbol* | *Atomic weight* | *Valency* |
|---|---|---|---|
| Hydrogen | H | 1 | 1 |
| Helium | He | 4 | 0 |
| Carbon | C | 12 | 4 |
| Nitrogen | N | 14 | 3 or 5 |
| Oxygen | O | 16 | 2 |
| Sodium | Na | 23 | 1 |
| Magnesium | Mg | 24 | 2 |
| Phosphorus | P | 31 | 3 or 5 |
| Sulphur | S | 32 | 2,4 or 6 |
| Chlorine | Cl | 35·5 | 1 |
| Potassium | K | 39 | 1 |
| Calcium | Ca | 40 | 2 |
| Iron | Fe | 55·8 | 2 or 3 |
| Copper | Cu | 63·5 | 1 or 2 |
| Zinc | Zn | 65·3 | 2 |
| Silver | Ag | 107·8 | 1 |
| Iodine | I | 127 | 1 |
| Gold | Au | 197 | 2 |
| Mercury | Hg | 200·6 | 2 |
| Lead | Pb | 207 | 2 |
| Radium | Ra | 226 | 2 |
| Uranium | U | 238 | 6 |

The idea of valency may also be extended to the case of a group of atoms which appears frequently as a sort of larger building block in the structure of a molecule. Thus, we have for instance, sulphuric acid, sodium sulphate and copper sulphate which are built up, on the one hand, of a group of 1 sulphur atom and 4 hydrogen atoms and, on the other, of 2 atoms of hydrogen, or 2 atoms of sodium, or 1 atom of copper, therefore these molecules are represented by $SO_4H_2$, $SO_4Na_2$, $SO_4Cu$. The group $SO_4$, or radical as it is called, has obviously a valency 2.

The above are a few examples of the way in which molecules are represented to indicate the atoms of which they are built up, and more will be given in this and subsequent chapters.

At times the structure of the molecule is represented in a more graphic manner by indicating the bonds or links between the various constituent atoms of a molecule. Monovalent atoms will have one link (or hook), thus, $H-$, $Cl-$; divalent atoms will have two links, thus, $-O-$, $-S-$; trivalent atoms will have three links and so on, thus, $=N-$, and $=C=$; then a water molecule $H_2O$ may be represented as $H-O-H$, hydrochloric acid $H-Cl$, ammonia $NH_3$ as  $H-N{<}^{H}_{H}$, carbon dioxide $CO_2$ as $O=C=O$.

**Chemical Equations.** When chemists want to produce a molecule consisting of several different atoms, they rarely choose the direct method of taking the right proportions of these various elements and mixing them under suitable conditions to obtain the required molecule. The reason why this rarely works is that most of these elements are not readily available in this state of separate atoms, but they exist in combination with other atoms, in one or other type of molecule. Therefore, the chemist will take two or more different types of molecules containing besides others the atoms he wants to combine, then he will mix these different types of molecules under suitable conditions of temperature, pressure etc., so that the constituent atoms of these molecules tend to break away from each other and recombine with atoms from some other molecule. Of course it is the art of the chemist to mix the right type of molecules in the right proportions and under suitable conditions so that these react on each other, as it is called, and the result of these chemical reactions are new molecules containing amongst others the one, or the ones wanted by the chemist. He will then further have to separate the wanted molecules from the unwanted ones. Such chemical transformations or reactions are represented by chemical equations, putting on the left hand side the original molecules and on the right hand side, the new molecules resulting from the chemical reaction. For instance, the chemical reaction in which sodium carbonate is mixed with hydrochloric acid and which results in the production of sodium chloride with water and carbon dioxide is represented by the equation,

$$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$$

You will find the same number of each type of atoms on each side. Of course in writing such equations some fundamental rules are to be followed. Only complete molecules take part in the reaction, therefore on either side complete molecules must be represented, thus hydrogen and chlorine combining to produce hydrochloric acid would be represented as $H_2 + Cl_2 \rightarrow 2HCl$, because both hydrogen and chlorine molecules contain two atoms each, the formation of water is written as $2H_2 + O_2 \rightarrow 2H_2O$, because the molecule of oxygen contains two atoms of oxygen etc. This will become clear by the numerous examples in the chapters that follow this.

We have already explained before that chemists have divided the elements into two series, the metals and non-metals because of the rather sharp differences between the two types. Similarly, the chemists have divided the chemical compounds into three categories each having its own characteristics; they are the acids, bases and salts. Before we begin to study these three categories it will be necessary to learn how they are derived.

**Oxides.** You already know that the change produced when a substance reacts with oxygen is called an oxidation. Both combustion and rusting are examples of oxidation. The former is an example of rapid oxidation, while the latter is an example of slow oxidation. In all oxidation reactions the substance formed as a result of the chemical combination of oxygen with one other element is called an oxide.

Oxygen reacts with non-metals as follows :

$S + O_2 \rightarrow SO_2$
(Sulphur) (Sulphur dioxide)
$C + O_2 \rightarrow CO_2$
(Carbon) (Carbon dioxide)
$4P + 5O_2 \rightarrow 2P_2O_5$
(Phosphorus) (Phosphorus pentoxide)

Oxygen reacts with metals as follows :

$4Fe + 3O_2 \rightarrow 2Fe_2O_3$
(Iron) (Ferric oxide)
$2Mg + O_2 \rightarrow 2MgO$
(Magnesium) (Magnesium oxide)
$2Na + O_2 \rightarrow Na_2O_2$
(Sodium) (Sodium peroxide)

Non-metallic oxides are called acidic oxides and sometimes acid anhydrides (the word anhydride means 'without water'). When acidic oxides are placed in water they dissolve to form acid solutions called acids.

Thus,

$SO_2 + H_2O \rightarrow H_2SO_3$
(Sulphurous acid)

$CO_2 + H_2O \rightarrow H_2CO_3$
(Carbonic acid)

$P_2O_5 + 3H_2O \rightarrow 2H_3PO_4$
(Phosphoric acid)

Metallic oxides are called basic oxides and sometimes basic anhydrides. When some basic oxides are placed in water they dissolve. The solutions, called hydroxides, are alkalies. The majority of basic oxides, however, such as oxides of iron, tin and copper are insoluble in water. The hydroxides of these metals are obtained by other methods. Since these hydroxides and the oxides from which they are derived, behave towards acidic oxides similarly as the basic oxides of other metals they are also called basic oxides.

Thus,

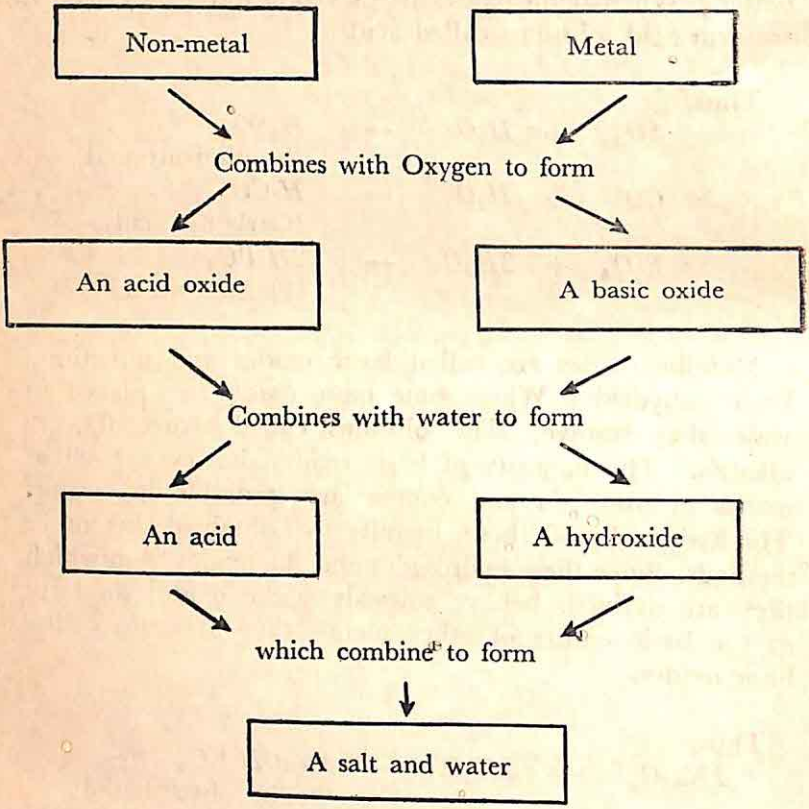
$2Na_2O_2 + 2H_2O \rightarrow 4NaOH + O_2$
(Sodium hydroxide)

$MgO + H_2O \rightarrow Mg(OH)_2$
(Magnesium hydroxide)

The compounds are called hydroxides, because they are compounds of a metal and the monovalent group—$OH$, called hydroxyl.

All acids combine with basic oxides and hydroxides to form a salt and water.

We can summarise what we have said in the following chart :



**Acids.** The acids commonly used in the laboratory are Hydrochloric acid ($HCl$), Sulphuric acid ($H_2SO_4$), Nitric acid ($HNO_3$), Carbonic acid ($H_2CO_3$) and Phosphoric acid ($H_3PO_4$).

An acid is defined as a chemical compound containing replaceable hydrogen atom or atoms in its molecule, a part or whole of which may be replaced by a metal or a group of elements acting like a metal, to produce a salt.

Sulphuric acid, for example, contains two replaceable hydrogen atoms in a molecule, one or both of which may be replaced by a metal such as sodium, or a group of elements which act like a metal, such as ammonia to produce the respective salt.

Thus,

$$NaOH + H_2SO_4 \rightarrow NaHSO_4 + H_2O$$

(Sodium bisulphate)

$$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$$

(Sodium sulphate)

$$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$$

(Ammonium sulphate)

An acid is characterised by its sour taste, its ability when soluble in water to change the colour of blue litmus to red, its vigorous reaction with basic oxides and hydroxides to produce a salt and water and its ability to liberate carbon dioxide from carbonates.

Thus,

$$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$$

(Sodium carbonate) (Sodium chloride)

Most acids (nitric acid is a notable exception) give hydrogen with the more reactive metals such as iron, magnesium and zinc. When this happens the hydrogen atoms in the acid molecule are replaced by the metal and salt is thereby formed.

Thus,

$$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$$

(Ferrous sulphate)

$$Zn + 2HCl \rightarrow \underset{\text{(Zinc chloride)}}{ZnCl_2} + H_2$$

$$Mg + H_2SO_4 \rightarrow \underset{\text{(Magnesium sulphate)}}{MgSO_4} + H_2$$

Acids should at all times be handled very carefully as they are corrosive, that is, they attack the skin and cause painful burns.

**Bases.** A base is defined as a chemical compound containing usually the oxide or the hydroxide of a metal, or of a group of elements acting like a metal, which can react with an acid to produce a salt and water. The reaction of a base with an acid is called neutralisation.

Thus,

$$\underset{\text{(Copper oxide)}}{CuO} + H_2SO_4 \rightarrow \underset{\text{(Copper sulphate)}}{CuSO_4} + H_2O$$

$$\underset{\text{(Zinc oxide)}}{ZnO} + 2HNO_3 \rightarrow \underset{\text{(Zinc nitrate)}}{Zn(NO_3)_2} + H_2O$$

$$\underset{\text{(Sodium hydroxide)}}{NaOH} + HCl \rightarrow \underset{\text{(Sodium chloride)}}{NaCl} + H_2O$$

$$\underset{\text{(Potassium hydroxide)}}{KOH} + HNO_3 \rightarrow \underset{\text{(Potassium nitrate)}}{KNO_3} + H_2O$$

$$\underset{\text{(Ammonium hydroxide)}}{2NH_4OH} + H_2SO_4 \rightarrow \underset{\text{(Ammonium sulphate)}}{(NH_4)_2SO_4} + 2H_2O$$

A base is characterised by its vigorous reaction with an acid to produce a salt and water, by its ability to set free ammonia from ammonium salts and by its ability when soluble in water, to change the colour of red litmus to blue. A solution of a base feels soapy to touch.

**Salts.** A salt is defined as a chemical compound which is produced when the hydrogen atom or atoms present in the molecule of an acid are replaced either partially or completely by a metal or a group of elements acting like a metal.

If the acid used is sulphuric acid the salt formed is called carbonate; if it is phosphoric acid the salt formed is called a phosphate; if it is hydrochloric acid the salt formed is called a chloride; if it is nitric acid the salt formed is called a nitrate.

**Common Salts we Use.** Sodium chloride ($NaCl$), commonly known as table salt, occurs in sea water, in some salt lakes and in the earth as rock salt. In the laboratory it is prepared by neutralising caustic soda with hydrochloric acid.

It is used to flavour food; in the preservation of fish, meat, and other foods; in the glazing of drain pipes and pottery; and in the manufacture of many chemicals such as sodium carbonate, caustic soda, chlorine and soda.

Sodium carbonate ($Na_2CO_3 . 10H_2O$), commonly known as washing soda, is obtained by heating pure sodium bicarbonate in a platinum vessel to a high temperature until the final weight is constant.

It is used for washing purposes, for the removal of permanent hardness in water, in the manufacture of soap, paper, glass and of chemicals such as caustic soda and other sodium compounds.

Sodium bicarbonate ($NaHCO_3$), commonly known as baking soda, is sometimes prepared by passing carbon dioxide through a solution of sodium carbonate. It is used in preparing certain kinds of medicines. A mixture of sodium bicarbonate and potassium hydrogen tartrate is sold under the trade name of baking powder.

Potassium permanganate ($KMnO_4$) commonly known as Condys, is prepared by heating equal quantities of caustic potash and pyrolusite (manganese dioxide) on a sand-tray in a nickel crucible until they melt. The substance formed is allowed to cool and then dissolved in a small amount of water. The resulting solution is green in colour. This solution is added to a large amount of water. The colour now changes to purple. When this purple solution is concentrated and crystallised, crystals of potassium permanganate are formed. This substance is used as a disinfectant and to purify drinking water.

Magnesium sulphate ($MgSO_4 . 7H_2O$), commonly known as Epsom salts, is prepared by the action of dilute sulphuric acid on either magnesium, or its oxide, or its hydroxide, or its carbonate. It is chiefly used in medicine as a purgative.

Ammonium carbonate $(NH_4)_2CO_3$, commonly known as Sal volatile, is prepared by heating a mixture of ammonium, sulphate and chalk until the mixture is red-hot and then condensing the vapours that are formed. It is chiefly used in the manufacture of smelling salts.

Sodium hydroxide ($NaOH$), commonly known as caustic soda, is prepared by the action of water on either sodium, or its monoxide or its peroxide. The solution obtained is boiled and filtered. When the filtrate is evaporated, caustic soda is obtained. It is used in the manufacture of sodium, soap, paper, artificial silk, in bleaching and in the purification of bauxite, the natural ore from which aluminium is obtained.

**Soap.** Soap is produced by boiling animal or vegetable fats or oil with caustic soda or potash. Fats, like lard or tallow, and oils, like coconut or palm oil, are used, these are chemical mixtures containing some complex acids which on combining with sodium hydroxide ($NaOH$) or potassium hydroxide ($KOH$) produce alkaline salts, which are soap.

Sodium hydroxide produces hard soap and potassium hydroxide produces soft, jelly-like soap.

When soap is dissolved in even a small quantity of water it has great cleaning properties, in particular, greasy dirt, is easily removed by its use.

The actual washing or detergent action of a soap solution has not yet been fully understood, an older simpler explanation having been proved unsatisfactory. This cleaning action is an intricate phenomenon including wetting, grease dissolving, keeping the dissolved dirt in small quantities (called emulsification), etc.

## CHAPTER ACTIVITIES

*Outdoors*

Visit a pharmaceutical works, a soap factory and a paper factory.

*For your wall newspaper*

Take photographs during your visits to the factories mentioned, and mount them on your board.

*Note-book exercise*

Write an account of your visit to any one of the factories mentioned.

*Laboratory work*

1. Collect several jars of oxygen.

Heat a piece of charcoal until it is red-hot and drop it into a jar of oxygen. Cover the jar and wait until the charcoal has ceased to burn. Pour a little lime-water into the jar. Note that the lime-water becomes milky showing that carbon dioxide has been formed as a result of the combustion of charcoal.

Repeat the above experiment and introduce some blue litmus into the jar instead of lime-water. Note that the colour of the litmus changes to red showing that carbon dioxide has acid properties.

Put some flowers of sulphur in a deflagrating spoon and heat it until the sulphur starts burning. Lower the burning sulphur into a jar of oxygen and cover the jar. Remove the sulphur after it has ceased to burn. Pour some blue litmus into the jar and note that its colour changes to red showing that the sulphur dioxide which is formed has acid properties.

Warm a piece of sodium metal over a bunsen flame until it melts. Lower it into a jar of oxygen. Pour a little water into the jar to dissolve the oxide formed and then add some red litmus. Note that the colour of the litmus changes to blue showing that the sodium peroxide which is formed has basic properties.

2. Take three test-tubes and pour a little dilute sulphuric acid in each. Add a few drops of blue litmus to the first test-tube and note that the colour of the litmus changes to red. Add a piece of zinc to the second test-tube. Note the effervescence which follows. Hold a lighted splint to the mouth of the test-tube. Note that there is a loud 'pop' and that the gas catches fire. The gas given off from the test-tube is hydrogen. The 'pop' is caused by the burning of a mixture of hydrogen and air which is explosive. Add a piece of marble to the third test-tube. Note the effervescence which follows. Hold a lighted splint to the mouth of the test-tube. The splint ceases to burn because the carbon dioxide given off does not allow things to burn in it. Dip a glass rod in lime-water and hold it so that a drop of lime-water forms at the end of it. Hold this drop near the mouth of the test-tube and note that the clear lime-water becomes milky.

Repeat the tests given for sulphuric acid as above with acids such as hydrochloric acid and nitric acid, metals such as iron, lead and copper, and carbonates such as lime and chalk. Enter your results in a table such as the one given below :

| *Substance* | *Effect of dilute acid used* | | |
|---|---|---|---|
| | $H_2SO_4$ | $HCl$ | $HNO_3$ |
| Litmus | | | |
| Zinc | | | |
| Iron | | | |
| Lead | | | |
| Copper | | | |
| Marble | | | |
| Lime | | | |
| Chalk | | | |

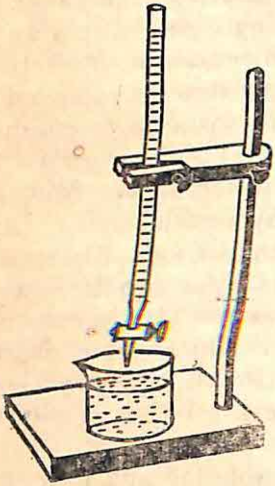
3. Pour some dilute sulphuric acid into an evaporating dish. Add small pieces of magnesium to the acid and stir the while. When no more magnesium dissolves in the acid, filter the solution into another evaporating dish. Evaporate the filtrate and inspect the crystals of magnesium sulphate that remain. We can infer that the magnesium has replaced the hydrogen in the sulphuric acid to form magnesium sulphate.

4. Take a beaker and pour some water in it. Add a small amount of caustic soda (sodium hydroxide) to it. Do not use your hands for this purpose as caustic soda, like most alkalis, is very corrosive. As caustic soda is put into the water there is an immediate rise in temperature. This is because it has a very great affinity for water. On account of this property the bottle in which it is stored is always kept closed. After you have made a weak solution of caustic soda you can test its properties.

Dip the tips of your fingers in the solution and note that it has a soapy feeling. Wash your fingers immediately after applying this test. Pour some of the solution into three separate test-tubes. Add a piece of zinc to the first test-tube, a piece of marble to the second test-tube and some ammonium chloride to the third test-tube. Heat each test-tube in turn. You will note that a strong smell of ammonia is given off from the third test-tube. Pour a few drops of red litmus into the beaker containing the solution and note that the colour changes to blue. Repeat the experiments with alkalis such as lime-water (calcium hydroxide), caustic potash (potassium hydroxide) and ammonium hydroxide.

5. You have read in your text that the reaction of a base with an acid to produce a salt and water is called neutralisation. By this reaction both the acid and the base destroy each other and produce substances which have neither acidic not basic properties.

Support a burette in the clamp of a retort stand and fill it with hydrochloric acid. Pour some caustic soda solution in a beaker and place it under the burette. Colour the caustic soda solution blue by adding a drop of red litmus to it. Now open the tap of the burette and allow the hydrochloric acid to run slowly into the beaker. Stir the contents of the beaker with a glass rod while acid is being added to it. Stop adding acid the moment *the colour changes to purple, that is,* a colour which is neither red nor blue. Neutralisation has now taken place for the contents of the beaker is neither acid nor alkaline. Evaporate the contents of the beaker and taste the salt crystals that remain. You will



*Neutralisation.*

find that its taste is like that of table salt, which indeed it is.

Repeat the above experiment using sulphuric acid or nitric acid and either caustic soda or caustic potash. Do not taste the salts produced.

6. In the preceding experiment salt was prepared by the neutralisation of an acid and a hydroxide. In this experiment we will prepare a salt from an acid and a basic oxide.

Pour some dilute sulphuric acid into an evaporating dish and warm it over a bunsen flame. While the acid is being warmed, add small quantities of copper oxide to it and stir the mixture with a glass rod. Filter the mixture into another evaporating dish when no more copper oxide will dissolve in it. Evaporate the filtrate and inspect the blue crystals of copper sulphate that remain.

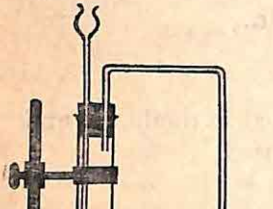
*At home*

Make a list of acids, bases and salts used in the home and indicate the purpose for which each is used.

## CHAPTER VII

# CHLORINE AND HYDROCHLORIC ACID

THE GAS Chlorine is named after its colour from the Greek word 'chloros' which means green. It is a very reactive element so much so that it does not occur in nature in the free state, but in combination with some metals especially sodium with which it unites to form sodium chloride. The gas finds many applications in everyday life, such as bleaching, chlorination, etc. The gas is poisonous and was the first poison gas to be used in war.



Preparation of chlorine.

**Preparation of Chlorine.** Chlorine is made by the oxidation of hydrochloric acid. During the reaction one atom of oxygen liberates two atoms of chlorine. Thus in the case of oxidation by manganese dioxide we have the following reaction.

$$MnO_2 + 4HCl \rightarrow MnCl_2 + Cl_2 + 2H_2O$$

Since chlorine is a very poisonous gas it is preferably prepared in a fume-cupboard.

Fill one-third of a flask with granular manganese dioxide. Fit a two-holed stopper to the flask. Insert a thistle funnel through one hole of the stopper and a delivery tube through the other. Support the flask by means of a retort stand and let the free end of the delivery tube dip into a gas jar. Pour concentrated hydrochloric acid through the thistle funnel until the flask is about half-filled. Warm the flask gently with a bunsen flame. Collect several jars of the gas by upward displacement of air.

**Properties of Chlorine.** Chlorine is a greenish yellow gas with a pungent smell. If inhaled it attacks the lining of the nose, throat and lungs.

Chlorine is fairly soluble in water and much denser than air. Because of this we collect the gas by upward displacement of air.

If a lighted candle is thrust into a jar of chlorine the candle continues to burn giving off thick smoke, the chlorine gas combining with the hydrogen of the paraffin of the candle, produces and sets free the carbon in the form of soot. The gas itself, however, does not combine with oxygen. A mixture of chlorine and hydrogen combines explosively in sunlight or if exposed to flame.

The gas is very reactive and combines with many metals to form the corresponding chlorides.

Damp chlorine bleaches litmus paper, grass, and ordinary ink, causing the colour of these substances to disappear. This is because chlorine reacts with water to form hydrochloric acid and hypochlorous acid ($HOCl$), the latter being an oxidising agent, liberates oxygen thus oxidisiing the dye and causing it to be bleached.

Chlorine is absorbed by, and reacts with, cold caustic soda to form sodium chloride and sodium hypochlorite ($NaOCl$). It reacts with hot caustic soda to form sodium chloride and sodium chlorate ($NaClO_3$). Sodium hypochlorite is the active ingredient in various household bleaches and is also used as a disinfectant, while sodium chlorate is used as a weed-killer, for conversion into potassium chlorate and as an active ingredient in throat lozenges because of its power to kill germs.

Chlorine reacts with dry slaked lime to form bleaching powder.

**Uses of Chlorine.** The gas is used for disinfecting the city water supply and also the water in public swimming baths. The proportion of one part of chlorine to a million parts of water is enough to kill in a few minutes all the disease germs present.

Another important use of chlorine is in the manufacture of bleaching powder used for bleaching cotton fabrics. When a fabric is to be bleached it is first made to soak in a dilute suspension of bleaching powder in water. It is next immersed in a bath of dilute hydrochloric acid during which stage it becomes bleached. Thereafter it is treated with a substance that takes up the excess chlorine and acid, called an antichlor, and finally the fabric is thoroughly washed with water.

Chlorine is used in the manufacture of many chemical compounds, such as carbon tetrachloride used as a solvent and in certain kinds of fire extinguishers, chloroform used as an anaesthetic, and compounds used for the production of plastics, dyes, flavours and insecticides.

**Preparation of Hydrochloric Acid.** Put some sodium chloride in a flask and fit the flask with a two-holed stopper. Insert a thistle funnel through one hole of the stopper and a delivery tube through the other. Support the flask on a retort stand. Connect the free end of the delivery tube to an empty flask and arrange a second delivery tube to connect the empty flask with a beaker of water as shown. Pour concentrated sulphuric acid down the funnel until the sodium chloride is covered. You will notice that there is a vigorous reaction at once. The gas evolved is hydrogen chloride and the solution of the gas in water is called hydrochloric acid.

Thus,

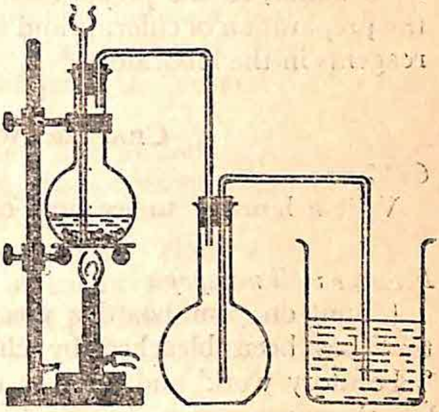
$$NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$$

When the initial vigorous reaction slackens, it will be necessary to gently warm the flask with a bunsen flame to maintain the flow of the gas. On strongly heating the flask the sodium bisulphate remaining in the flask reacts with the remaining sodium chloride to produce sodium sulphate and more hydrochloric acid.

Thus,

$NaHSO_4 + NaCl \rightarrow Na_2SO_4 + HCl$

The empty flask placed between the generating flask and the beaker guards against the suction of water into the generating flask. It thus serves as an anti-suction device. Due to the great solubility of hydrogen chloride there is the possibility that reduction of pressure within the generating flask might occur. In the absence of the empty flask the difference of pressure would cause the water in the beaker to be sucked into the generating flask and as the water comes into contact with the hot concentrated sulphuric acid an explosion would take place.



*Preparation of hydrochloric acid.*

**Properties of Hydrochloric Acid.** This acid, like all other acids, changes the colour of blue litmus to red; reacts with bases to give salts (chlorides) and water; produces salts (chlorides) and carbon dioxide with carbonates and reacts with most metals to give salts (chlorides) and hydrogen.

Hydrochloric acid can be distinguished from the other acids by the fact that when silver nitrate is added to it a white curdy precipitate forms.

As we have seen, when concentrated hydrochloric acid is warmed with an oxidising agent it is oxidised to chlorine.

When concentrated hydrochloric acid is exposed to air it loses hydrogen chloride which is given off in fumes.

**Uses of Hydrochloric Acid.** The acid is used for cleansing metal surfaces before they are galvanised, electroplated, tinned or enamelled; in the preparation of dyes, drugs and photographic chemicals; in the extraction of glue from bones; in the preparation of glucose from starch; in the preparation of chlorine and as one of the most important reagents in the laboratory.

## Chapter Activities

*Outdoors*

Visit a laundry to see how cotton fabrics are bleached.

*For your wall newspaper*

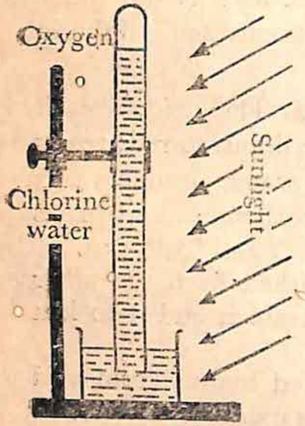
Mount on your board a piece of coloured cotton cloth that has been bleached by chlorine as described under 'laboratory work' and another that has been bleached by bleaching powder as described under 'at home'.

*Note-book exercise*

Write a summary of this chapter.

*Laboratory work*

1. Pass chlorine into a beaker of water until the water becomes greenish in colour. Fill a long tube with this chlorine water and invert it into a beaker containing some of the chlorine water. Support the tube by means of a retort stand and expose the apparatus to sunlight. After a few days you will notice that a gas has collected in the tube. By means of a glowing splint you can ascertain that this gas is oxygen.



*To show the effect of sunlight on chlorine water.*

When the apparatus was exposed to sunlight the chlorine combined with the hydrogen part of the water to form hydrogen chloride and oxygen. The hydrogen chloride dissolved in the water to form hydrochloric acid, while the oxygen bubbled to the top of the tube.

2. Collect several jars of chlorine and perform the following experiments to test the properties of the gas.

Lower a lighted taper into a jar of the gas and note what happens.

Heat a piece of iron wire and lower it into a jar of the gas. Note that the iron becomes red-hot as it combines with chlorine to form ferric chloride.

Put a dry piece of coloured cotton cloth into a jar of the gas and a damp piece of coloured cotton cloth into another jar. Note that the damp cloth is bleached.

*At home*

Add some bleaching powder to a tumbler of water and stir the mixture. Pour some dilute hydrochloric acid in a second tumbler. Wet a piece of coloured cotton cloth and soak it in the first tumbler for about ten minutes. Then wash the cloth in water and allow it to soak in the second tumbler for about 5 minutes. Then wash the cloth with water again. At the end of the process, the cloth should be white. If traces of colour remain the process should be repeated.

## CHAPTER VIII

# SULPHUR AND PHOSPHORUS

SULPHUR is found free in nature and also in combination with metals in various sulphides. This element has been used by man for 4,000 years. At the present time it still ranks among the most important substances of the chemical industry.

**Uses of Sulphur.** Sulphur is used in the manufacture of sulphuric acid and sulphur dioxide. The uses of these chemicals are numerous and will be discussed later in this chapter.

A large amount of sulphur is used by the rubber industry. It is mixed with rubber and the mixture is heated. This process, known as vulcanisation, makes the rubber tough and flexible over a wide range of temperature. Rubber that has not been vulcanised tends to become sticky when subjected to a high temperature, and brittle when subjected to a low temperature.

Sulphur is used either alone or mixed with lime to dust fruit trees and bushes as a protection against certain kinds of fungi and insects. It is mixed with charcoal and potassium nitrate to make gunpowder. It is combined with sand to make a water-proof cement, and combined with carbon to make an acid-resistant material.

Sulphur compounds are used in the manufacture of dyes, drugs, ointments, paints, varnishes, fertilisers, matches, plastics, synthetic textiles, food products and so on. Among this list the drugs made from sulphur in recent years have given man new hope in his fight against bacterial infection.

**Sulphur Dioxide.** We already know that sulphur dioxide is formed when sulphur burns in air or oxygen. In the laboratory, the gas is formed by heating copper in the form of copper filings with concentrated sulphuric acid in a flask and collecting the gas evolved by the upward displacement of air. The reaction is represented by the following equation,

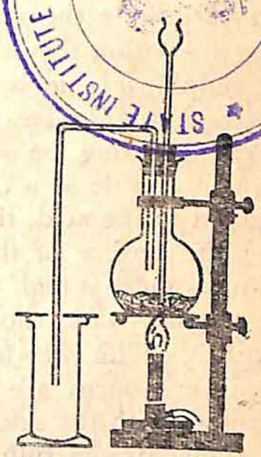
$$Cu+2H_2SO_4 \rightarrow CuSO_4+2H_2O+SO_2$$

The most important use of sulphur dioxide is in the manufacture of sulphuric acid.

Since sulphur dioxide is fairly poisonous and destroys disease germs it is used as a fumigant.

The gas has been used from ancient times as a bleaching agent. Animal fibre fabrics such as silk, wool or feathers which would be damaged by a strong bleaching agent such as Chlorine, are bleached by sulphur dioxide. Woodpulp for newspapers is also bleached by this gas.

Since sulphur dioxide is easily liquefied and vaporised it was once used as a refrigerant. It has, however, been replaced by substances that are less poisonous and less corrosive.



*Preparation of sulphur dioxide.*

Sulphur dioxide is used in the manufacture of carbon bisulphide which is used in the treatment of wood-pulp in the early stages in the manufacture of paper and artificial silk.

**Sulphuric Acid.** This acid is commonly called oil of vitriol on account of its oily appearance. It is colourless when pure and yellowish when containing impurities. It does not fume and is odourless.

When sulphuric acid is exposed to air it takes up moisture, because of its strong affinity for water. On account of this property it is said to be hygroscopic and is used for drying gases with which it does not react.

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Besides combining with water directly, it can also remove the component elements of water from certain substances. It is therefore called a dehydrating agent. Thus when it is added to sugar, wood, paper, cloth or flesh it combines with the elements of water in these substances and changes them to pure charcoal. When added to crystals of copper sulphate, it combines with the elements of water in the crystals. As the crystals are deprived of their water of crystallisation they change in colour from blue to white.

Sulphuric acid is denser than water, its specific gravity being 1·8. It mixes with water giving out tremendous heat. When diluting the acid, care must be taken to add it to the water, a little at a time, with constant stirring. If water is added to the acid, the water being less dense tends to float on the surface of the acid. The heat evolved where the liquids meet is high enough to make the water boil. Consequently, water shoots out of the vessel bringing the acid with it. This may lead to serious accidents.

Severe burns are caused if sulphuric acid comes into contact with the skin, as it is very corrosive.

Concentrated sulphuric acid does not react with metals when cold, but reacts with most metals when it is hot. We have seen how sulphur dioxide is evolved when copper is heated with concentrated sulphuric acid; the copper sulphate produced in the reaction remains in the generating flask.

Dilute sulphuric acid shows all the properties of an ordinary acid. It changes the colour of blue litmus to red; it reacts with most metals to form salts (sulphates) and hydrogen; it reacts with bases to form salts (sulphates and water and it reacts with carbonates to form salts (sulphates) and carbon dioxide.

Sulphuric acid is recognised by the white precipitate of barium sulphate which forms when barium chloride is added to it.

When small quantities of sulphuric acid are heated, dense white fumes of sulphur trioxide are formed.

Sulphuric acid is one of the most important chemicals used in industry. Only its most important uses will be mentioned here.

Like hydrochloric acid, sulphuric acid is also used for cleaning metal surfaces before they are galvanised, electroplated, tinned or enamelled.

Chief among the products manufactured with the help of sulphuric acid are fertilisers such as superphosphate of lime and ammonium sulphate, rayon, paper, drugs, dyes, paints, glucose, glycerine, glue, explosives and various chemicals, the most important among them being nitric acid.

The acid is also used in refining oil and petroleum products. Accumulators used in cars, electric lighting sets, wireless sets and so on are filled with the acid.

**Sulpha Drugs.** One of the most important advances in medicine was made in the late thirties when it was discovered that some special compounds of sulphur had the property of keeping alive mice infected with streptococci, one of the most dangerous types of microbes. Very soon after, a whole series of sulpha compounds called sulphonamides or sulpha drugs were put on the market, which very effectively cured such serious diseases as pneumonia and septicemia, which up to then had frequently been fatal.

Since then the search has gone on for other sulpha drugs to cure other serious diseases. In the later years a special sulpha drug has been produced which may be effective in the treatment of tuberculosis.

Another impressive discovery in this line is that of the sulphones, a new set of sulpha drugs that has been found more effective against leprosy than any drug previously tested. In fact there is every hope that by the use on a mass scale of this new type of sulpha drug, which happens to be cheap, the dreaded disease of leprosy may be finally eradicated from the various tropical countries where it is still so widely spread.

**Phosphorus.** There are two forms of phosphorus, the very active white or yellow form and the much less active red form. White phosphorus is a waxy, translucent solid which is usually stored under water because it is highly poisonous and active enough to catch fire spontaneously in air. Red phosphorus is a powder which is not poisonous and must be heated to a higher temperature before it will burn.

**Matches.** The head of an ordinary safety match consists of an oxidising agent such as potassium chlorate and a substance which is easily oxidised such as antimony sulphate. Both these substances are held together with glue. The match-striking side of the match-box is coated with a mixture of red phosphorus, glass dust and glue. The red phosphorus catches fire when its temperature has been raised sufficiently; the glass dust provides a rough surface which serves to cause a high friction and consequently a high temperature and the glue serves to hold the substances together. When a match is struck, the oxidising agent is ground in close contact with the red phosphorus. As a result of the heat of friction a reaction occurs and the match catches fire. Since the igniting agent (red phosphorus) is separated from the oxidising agent (potassium chlorate) there is no danger of the matches catching fire spontaneously.

**Phosphorus Fertilisers.** Phosphorus is among the elements needed for plant growth. Although this element is present in the soil as a compound, called calcium phosphate, this is useless to plants because it is not very soluble in water. When, however, this calcium phosphate is treated with sulphuric acid, an acid phosphate called superphosphate of lime is produced which is soluble enough to be available to plants.

## CHAPTER ACTIVITIES

*Outdoors*

1. Visit a factory where rubber goods are made to see how rubber is vulcanised.
2. Visit a match factory.

*For your wall newspaper*

Take photographs during your visit to the match factory and arrange these photographs on your board so that they tell the complete story of how matches are made.

*Note-book exercise*

Describe in detail how matches are made.

*Laboratory work*

1. Collect several jars of sulphur dioxide. Perform experiments to determine the effects of the gas on (*a*) a burning candle; (*b*) water; (*c*) litmus; (*d*) coloured silk; (*e*) a small bundle of straw; (*f*) a few coloured feathers and (*g*) some wool.

2. Perform the following experiments to test the properties of concentrated sulphuric acid.

Pour some concentrated sulphuric acid into a beaker and weigh it. Expose the acid to air for a few days and reweigh it. Note the increase in weight due to the moisture absorbed from the air.

Cautiously add a small quantity of concentrated sulphuric acid to a beaker of water and stir the mixture continuously. Feel the outside of the beaker. You will notice that there is a very great evolution of heat within the beaker.

Place a spoonful of sugar in a crucible. Pour some concentrated sulphuric acid over the sugar. Note that the sugar becomes charred and a spongy black mass of charcoal is produced. The entire mass becomes very hot during the reaction and steam is evolved. Repeat the experiment with wood, cloth and paper.

*At home*

Collect information from encyclopaedias and general knowledge books for a class discussion on the subject of how man learned to make fire.

## CHAPTER IX

## NITROGEN AND ITS COMPOUNDS

IN ORDER to maintain our present nutrition standards and to increase these standards it is essential to increase the productivity of the land. One of the most important ways of doing this is through the effective use of nitrogen compounds.

Nitrogen is ranked among the three major elements needed by plants, the other two being phosphorus and potassium. It is needed not only by plants, but by every other living thing.

Although about 80 per cent of the atmosphere is nitrogen, this source of supply of the element is useless to plants as they can only absorb it in the form of its soluble compounds that are present in the soil. Nitrogen is, however, an inert gas, that is, it does not readily combine with other elements. Besides occuring as a gas in the free state in the atmosphere, nitrogen also occurs in nature in combination, especially as ammonia, $NH_3$, and as nitrates of potassium and sodium, $KNO_3$, known as nitre, and $NaNO_3$, known as chile salt petre. The cycle of uses and renewal of the nitrogen present in the atmosphere of which you will read in this chapter, reveals a miracle of balance involving an intricate interplay of the earth, air and living things.

**Properties of Nitrogen.** We know from experience that nitrogen is a colourless, odourless and tasteless gas, since the air containing so much nitrogen is such. Since it is inert it does not readily combine with the other gases present in the atmosphere thus making life possible on the earth. Moreover, the large proportion of nitrogen in the atmosphere serves to dilute the oxygen which would otherwise be too concentrated for the respiration of all living things.

Although nitrogen does not readily combine directly with most elements, however, at more or less high temperatures it combines with a certain number of metals to form nitrides with the emission of heat. Thus,

$3Mg + N_2 \rightarrow Mg_3N_2$ (Magnesium nitride)

$3Ca + N_2 \rightarrow Ca_3N_2$ (Calcium nitride)

Under suitable conditions nitrogen combines with hydrogen to form ammonia.

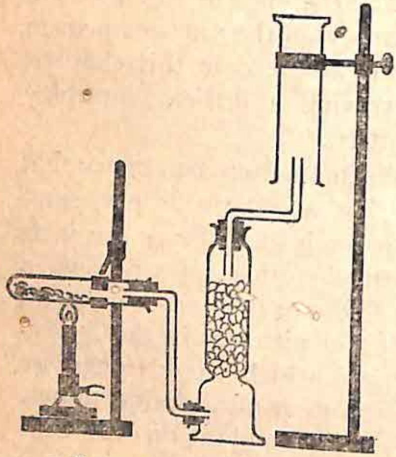
$N_2 + 3H_2 \rightarrow 2NH_3$

**Ammonia** ($NH_3$). It is a colourless gas with a pungent odour and soapy taste, often detected near stables and urinals. In fact large quantities of ammonia pass continually into the atmosphere as the result of putrefaction of animal and vegetable products, the respiration of animals and the combustion of coal.

Ammonia was originally produced by heating camel's dung, or by the distillation of hoofs, horns of stags, etc., preferably with lime.

Ammonia is prepared in the laboratory by heating any ammonium salt with any alkali.

Mix dry powdered ammonium chloride with twice its weight of dry slaked lime and put the mixture in a hard glass test-tube. Clamp the test-tube in a retort stand in a horizontal position and fit a one-holed stopper to it. Pass one end of a delivery tube through the stopper and connect the free end of the tube to a tower containing quicklime. Fit another delivery tube to the outlet of the tower and fix a gas jar over it as shown in the illustration. Carefully heat the mixture



*Preparation of ammonia.*

in the test-tube and collect the gas by downward displacement of air. The reaction is represented by the following equation :

$$2NH_4Cl + Ca(OH)_2 \rightarrow 2NH_3 + CaCl_2 + 2H_2O$$

The gas evolved is dried by means of the quicklime in the tower.

Since ammonia is lighter than air and very soluble in water it is collected by the downward displacement of air. It does not burn in air nor does it support combustion. The colour of red litmus changes to blue in the gas. Ammonia neutralises acids to form ammonium salts. Thus,

$$\begin{aligned} NH_3 + HCl &\rightarrow NH_4Cl \\ 2NH_3 + H_2SO_4 &\rightarrow (NH_4)_2SO_4 \\ NH_3 + HNO_3 &\rightarrow NH_4NO_3 \end{aligned}$$

A mixture of ammonia and oxygen is explosive.

Ammonia is exceptionally soluble in water forming ammonium hydroxide.A very strong solution of ammonium hydroxide is called liquor ammonia. When this liquid is heated, ammonia comes out of the solution.

Liquefied ammonia is used as a refrigerating agent while aqueous ammonia is used as a cleansing agent. Ammonia is also used in the manufacture of sodium carbonate and various ammonium salts.

Ammonia is produced on a commercial scale as a by-product in the manufacture of coal gas.

In World War I, the Germans had a great need for nitrogen compounds for the manufacture of ammunition. To supply this need they used Haber's synthetic process to manufacture ammonia by directly combining hydrogen with the nitrogen from the atmosphere, compressing the mixture of the two under high pressure and heating it to a high temperature in a chamber containing fine iron as a catalytic agent.

**Ammonium Salts.** As you have read, ammonia neutralises acids to form salts. All these salts are white crystalline solids. When these salts are heated they sublimate, that is change directly from solid to vapour. When the vapour is condensed it changes directly back to the solid.

Ammonium chloride is used in dry electric batteries; in medicine; in the preparation of solders; in the textile industry; in galvanising iron and in tinning copper.

Ammonium sulphate is used as a fertiliser and in the preparation of alum.

Ammonium carbonate known as sal volatile, has already been mentioned in Chapter 6.

Ammonium nitrate is used in the manufacture of fireworks, as a 'freezing mixture' and as a fertiliser.

**Nitric Acid.** Pure nitric acid, known as 'aqua fortis' is a fuming hygroscopic liquid with a choking smell and a sour taste. It is colourless, but if it decomposes even slightly to nitrogen dioxide its colour is likely to be tinged brown.

Nitric acid shows all the properties of an ordinary acid, that is, it is very corrosive; it changes the colour of blue litmus to red; reacts with carbonates to form salts (nitrates) and carbon dioxide; and reacts with bases to form salts (nitrates) and water. This acid, however, rarely reacts with metals to give off hydrogen. This is because it is an oxidising agent. When nitric acid reacts with metals such as iron, chromium and aluminium a thin layer of oxide forms on the surface of the metal. This layer prevents the reaction from proceeding any further. Dilute nitric acid reacts with metals such as copper and lead to form nitric oxide ($NO$); if the acid is concentrated, nitrogen dioxide ($NO_2$) is evolved.

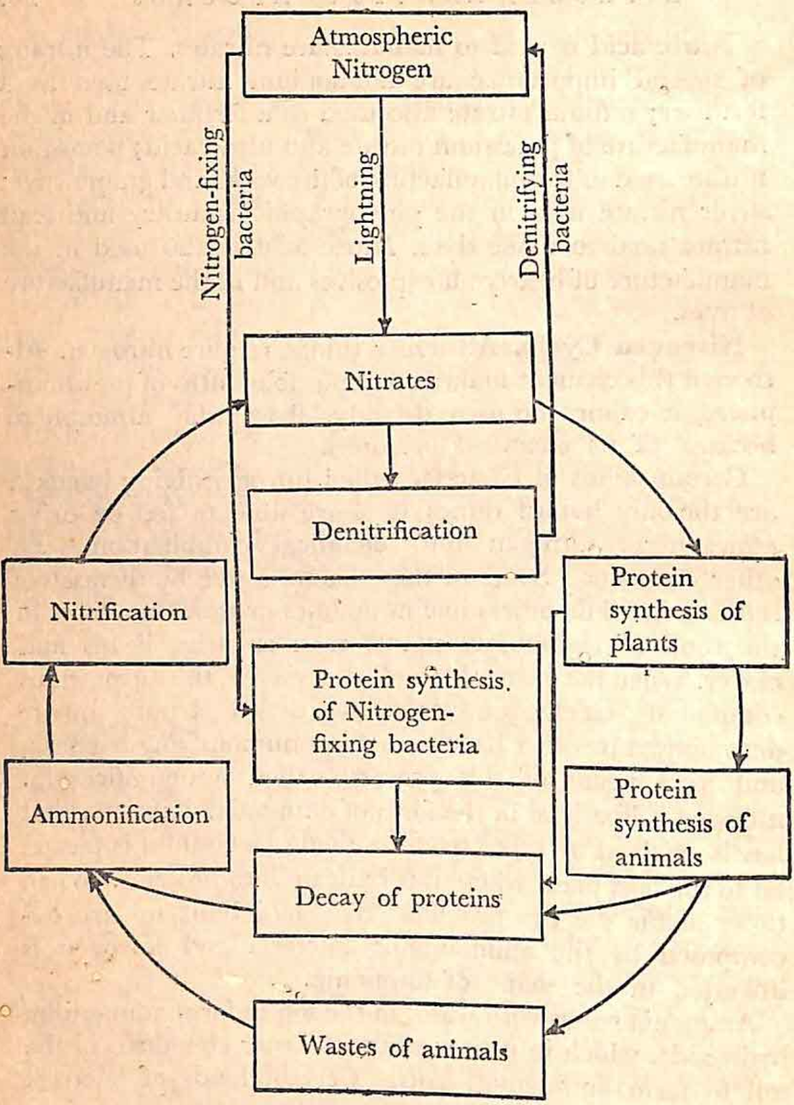
The fact that nitric acid is a powerful oxidising agent can be seen from its reaction with non-metals. Carbon, sulphur and red phosphorus are oxidised by warm nitric acid.

Nitric acid is used to manufacture nitrates. The nitrates of special importance are ammonium nitrate used as a fertiliser; sodium nitrate also used as a fertiliser and in the manufacture of potassium nitrate and nitric acid; potassium nitrate used in the manufacture of fireworks and gunpowder; silver nitrate used in the photographic industry and lead nitrate used to make dyes. Nitric acid is also used in the manufacture of nearly all explosives and in the manufacture of dyes.

**Nitrogen Cycle.** All living things require nitrogen. Although this element makes up about four-fifths of the atmosphere, it cannot be used directly from the atmosphere because of its chemical inertness.

Certain kinds of bacteria, called nitrogen-fixing bacteria are the only livings things that are able to 'fix' or bring atmospheric nitrogen into chemical combination with other elements. Some of these bacteria live by themselves in the soil, while others live in nodules or small swellings in the roots of leguminous plants such as peas, beans and clover. When the former kind of bacteria die, the nitrogenous compounds, chiefly proteins, which they had built up are decomposed by other bacteria, called ammonifying bacteria, and as a result of this process, called ammonification. nitrogen is liberated in the form of ammonia. Nitrogen that has been fixed by those bacteria living in nodules is passed on to the host plant where it is built up into proteins. When these plants die the proteins they had built up are decomposed by the ammonifying bacteria and nitrogen is liberated in the shape of ammonia.

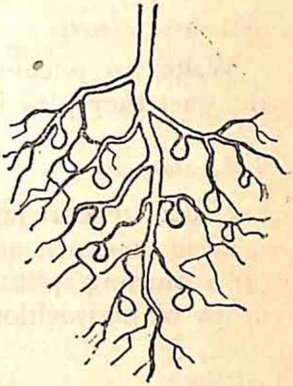
Ammonia reacts with water in the soil to form ammonium hydroxide, which in turn reacts with other chemicals in the soil to form ammonium salts. Certain kinds of bacteria called nitrifying bacteria convert ammonia or ammonium salts to nitrates which are readily utilised by plants of all kinds.



*The Nitrogen Cycle.*

The second natural way in which nitrogen becomes 'fixed' is by lightning flashes during a thunderstorm. The discharge of electricity brings about a combination of some oxygen and nitrogen in the atmosphere to form oxides of nitrogen. These oxides combine with water to form weak nitric acid. When the acid is carried down by the rain into the soil it reacts with certain bases in the soil to form nitrates.

The nitrates in the soil are absorbed by plants and built into proteins. Man and animals eat plants and build up their own body proteins from what they have obtained from plants.



*Nodules on the roots of a leguminous plant.*

When plants and animals die the proteins they had built up are decomposed by the ammonifying bacteria and nitrogen is liberated as ammonia. Furthermore, animals restore nitrogen compounds to the soil in their wastes, which after ammonification and nitrification become available to plants as nitrates.

Present in the soil are also certain kinds of bacteria called denitrifying bacteria which convert nitrates into gaseous nitrogen which escapes into the atmosphere.

### CHAPTER ACTIVITIES

*Outdoors*

1. Examine the roots of peas and beans for nodules.
2. Visit a fertiliser factory.

*For your wall newspaper*

Take photographs during your visit to the fertiliser factory and arrange these photographs on your board so that they tell the complete story of how fertilisers are made.

*Note-book exercise*

Write an account of nitrogen fertilisers, emphasising the part they play in the nation's economy.

*Laboratory work*

Collect several jars of ammonia.

Perform experiments to show the effects of the gas on (*a*) a burning splinter; (*b*) water; (*c*) litmus and (*d*) a few drops of hydrochloric acid.

*At home*

Make a scrapbook of the fertiliser industry in our country.

## CHAPTER X

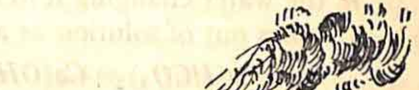
# LIME AND ITS PRODUCTS

CALCIUM carbonate is one of the most common and important substances used in industry. It is found in nature as chalk, limestone and marble. Vast quantities of these substances are found in most parts of the world as mountains or cliffs.

**Quicklime.** When either chalk, limestone or marble is heated strongly, carbon dioxide is given off and a white residue is left called quicklime or calcium oxide. The process by which this is done is called limeburning. Thus,

$$CaCO_3 \rightarrow CaO + CO_2$$

Limeburning is done in a kiln which is a clay structure at the bottom of which is a grate. Limestone or chalk packed into this structure is heated by a fire from below. The smoke and carbon dioxide that forms escapes from a chimney at the top of a kiln. After the kiln has been allowed to cool, the quicklime is removed.



*Section of a lime kiln.*

Quicklime is a white solid. If a little water is added to it a chemical reaction takes place during which heat is evolved and the quicklime combines with water to form a soft, white powder called slaked lime or calcium hydroxide. Thus,

$$CaO + H_2O \rightarrow Ca(OH)_2$$

When quicklime is strongly heated it emits a brilliant, light called limelight, which is used in searchlights.

Quicklime is used to produce slaked lime.

**Slaked Lime.** When quicklime is exposed to the air it absorbs moisture and gradually changes to slaked lime. When slaked lime is exposed to the air it absorbs carbon dioxide and after sometime changes to chalk. Thus,

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

Dry slaked lime absorbs chlorine to form bleaching powder.

When slaked lime is added to hard water in the proper proportions, it combines with the soluble calcium bicarbonate in the water changing it to insoluble calcium carbonate which comes out of solution as a precipitate. Thus,

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2O$$

The process of adding slaked lime to hard water is called Clark's process and is used to soften water on a large scale.

If more than the proper amount of slaked lime is added to the water it will become hard again, since slaked lime itself is a soluble calcium compound.

Slaked lime is used to manufacture mortar and bleaching powder. Milk of lime is used for whitewashing houses, in agriculture and to soften water.

**Mortar.** This is a mixture of sand, water and slaked lime. The proportions of sand and slaked lime that are mixed together vary according to the purpose for which the mortar is used. Sand is used to make the mortar porous while water serves to make the mortar into a paste.

When mortar is exposed to the air the water evaporates and carbon dioxide is absorbed. After a few days the slaked lime in the mortar changes to chalk. After this has happened the mortar is said to have 'set'. While it is setting, the water in the mortar evaporates. The water vapour thus given off condenses to water and is seen to trickle down the sides of the mortar. When this happens the mortar is said to 'sweat'. If you have ever entered a newly built house you would have noticed that the building is cool and damp. This is due to the sweating of the mortar.

Mortar is used by builders to join bricks together. It is used while it is soft and wet. As it dries, it absorbs carbon dioxide from the air and hardens binding the bricks firmly together.

**Plaster.** Quicklime is mixed with sand and water in the proper proportion to make plaster. The hair of cows is often added for better binding.

**Cement.** This building material of high binding qualities is obtained by burning a mixture of limestone and clay, the resultant mass, called clinker, is ground into powder and sieved, the final result being a fine greyish powder, well known to all who have watched modern building operations.

Cement is essentially a compound of lime, silica, alumina and iron oxide, the proportion of lime being about 65 per cent.

Cement mixed with sand and a small amount of water, to make it into a paste, sets and hardens rapidly, forming an excellent binding material which is now rapidly displacing mortar in the construction of brick buildings. However, the main use of cement is in the production of concrete. Gravel, sand and cement are mixed in the right proportions with a small quantity of water, turning it into a plastic mass which can be given various shapes by pressing it into forms. The concrete sets rapidly and grows very hard. It can be made into large monolithic blocks which have high compressive strength and great durability and adequate tensile strength to ensure cohesion.

To improve the tensile strength and assist in resisting shearing stress a network of iron or steel rods is frequently incorporated in the concrete to produce what is called 'reinforced concrete' or 'ferro-concrete'.

**Lime in Agriculture.** Lime is an important constituent of the soil. When plants are burnt and the ash formed is chemically analysed, it is seen that there is a high percentage of lime in the ash thus indicating its importance as a plant food.

The application of lime to the soil is called liming. It is applied either in the form of chalk or slaked lime or quicklime.

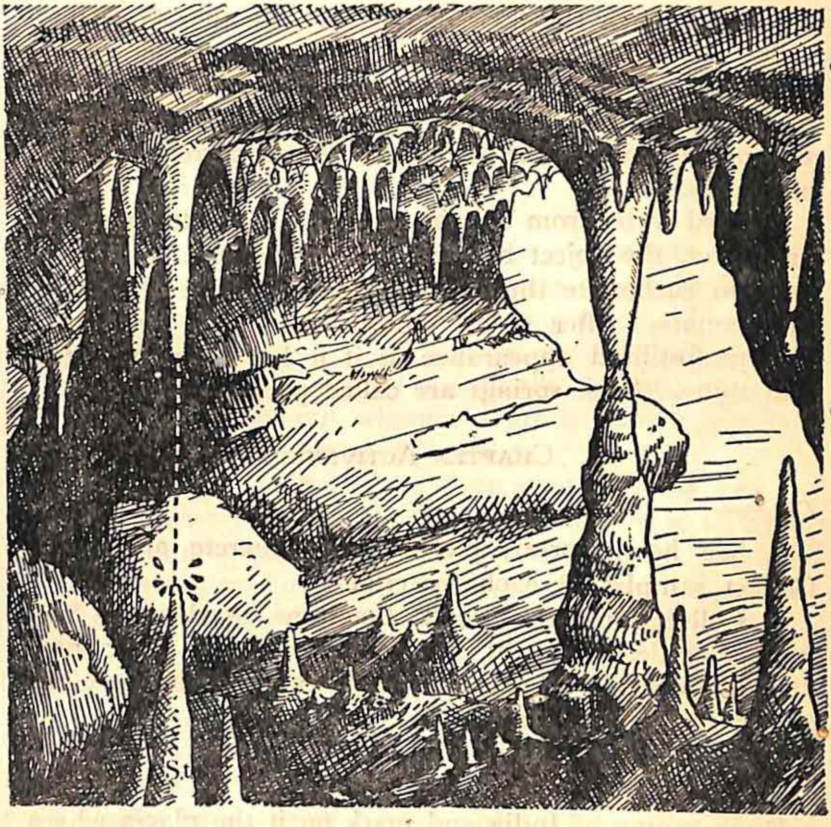
Since the lime in the soil is constantly washed out of the soil by the rain or absorbed by plants which may be removed by the farmer, it often requires renewal. Lime is added to the soil when there is a deficiency of it in the soil, in the farming of 'heavy' clays and to sweeten 'sour' land.

Lime acts in combination with other minerals in the soil as an important plant food. It is especially favourable to the production of nitrates since it assists in the decay of vegetable matter and helps the action of the nitrifying bacteria.

If the soil has excess acid in it, it is said to be 'sour'. Lime neutralises the acid and thus 'sweetens' 'sour' soil. The texture of a heavy clay soil is greatly improved by the addition of lime as this substance makes small particles of clay flocculate, that is, stick together in clusters. Consequently, the soil becomes more porous thus improving its absorbing power and allowing the free passage of air. Finally, lime destroys insects and larvae in the soil thus lessening the possibility of plant diseases.

**Stalactites and Stalagmites.** Limestone districts are well known for their remarkable caves. These caves have been formed by underground streams.

We already know that although calcium carbonate is insoluble in pure water yet it will dissolve in carbonic acid i.e., in a solution of carbon dioxide in water. As rain falls through the air it dissolves carbon dioxide and reaches the soil as a weak solution of carbonic acid. As the rain water passes through the soil it dissolves still more carbon dioxide and the solution of carbonic acid becomes stronger. If this solution reaches a bed of limestone, that is, calcium carbonate, it dissolves a little of the calcium carbonate as it



*Stalactites (S) and stalagmites (St.).*

percolates through the bed and forms a solution of calcium bicarbonate. As this solution slowly drips from the roof of a cave, part of the water from each drop evaporates and some of the bicarbonate decomposes to calcium carbonate, carbon dioxide and water. In this way small quantities of calcium carbonate are left behind as a deposit after the drop has fallen. During the course of many centuries the deposit grows from the roof downwards in the shape of an icicle. It is called a stalactite. Below each stalactite, where the drops reach the floor of the cave, another formation, called a stalagmite appears. Sometimes a stalactite may unite with a stalagmite to form a pillar. Both formations may assume fantastic shapes due to slight variations in the flow of water and in the direction of the air currents blowing about them.

If hard water from certain springs is made to drip over an object, the object becomes coated with a deposit of calcium carbonate through the decomposition of calcium bicarbonate. After a few months the object presents a curious fossilised appearance as if it has been converted into stone. Such springs are called petrifying springs.

### CHAPTER ACTIVITIES

*Outdoors*

1. See how mortar, plaster and concrete are made. Collect samples of each material.
2. Collect samples of chalk, limestone, marble, the 'fur' from a kettle, egg-shells, lime and sea-shells. Pour some dilute hydrochloric acid on each sample and test the gas evolved with lime-water.

*For your wall newspaper*

Draw a map of India and mark on it the places where chalk, limestone and marble are to be found.

*Note-book exercise*

Write a summary of this chapter.

*Laboratory work*

1. Place a few small pieces of chalk (not blackboard chalk) in a hard glass test-tube and fit a one-holed stopper to the mouth of the test-tube. Insert a delivery tube through the stopper. Heat the test-tube over a bunsen flame until it is red-hot. Bubble the gas that is given off through a test-tube containing lime-water. Note that the lime-water becomes milky showing that the gas is carbon dioxide. Collect the gas in another test-tube and introduce a burning splinter into the gas. You will find that the splinter is extinguished. After chalk has been heated sufficiently it changes to quicklime.

Allow the test-tube to cool and transfer the quicklime to a porcelain crucible. Add a few drops of water to it. Note that heat is evolved and the quicklime begins to 'steam'. This is due to a chemical reaction taking place as quicklime changes to slaked lime. Add a little more water and note that the solid swells, cracks and finally falls to a powder.

2. You can find out whether a given sample of soil is acid or alkaline by means of litmus paper.

Place a small portion of the given sample in a saucer and moisten it with water. Place over the moistened soil a piece of blue litmus paper and a piece of red litmus paper. Note the change in colour of the litmus papers.

3. Take a sample of sour soil and thoroughly mix it with an equal quantity of slaked lime. Test the sample now with litmus as in No. 2.

4. Test a given sample of soil for limestone by adding dilute hydrocholoric acid to it. Collect the gas evolved and find out if it is carbon dioxide. Although there are other substances besides limestone that react with acids causing effervescence, yet we may be reasonably sure that the substance

causing the effervescence is lime, as it is the only substance that is likely to be present in the soil in any quantity.

5. Take two wide glass jars and put powdered clay in one jar and a mixture of clay and slaked lime in the other. Pour some water in each jar, stir vigorously and then allow the contents to settle. Note that the contents of the jar to which lime was added settle first because the particles of clay are stuck together and are therefore heavier.

*At home*

Obtain some dry slaked lime and mix it with twice the amount of sand. Make the mixture into a paste by adding water. Mould it into a suitable shape by means of an old knife. Allow the mortar you have made to dry.

## CHAPTER XI

# NUTRITION IN PLANTS AND ANIMALS

ALL living things require food to provide for the growth and repair of the body tissues, to supply energy, to do work, to protect the body against diseases and to regulate the healthy working of the various systems. The processes by which a living thing is able to form new material from the constituents of its food is called nutrition.

Since the composition of protoplasm is the same in plants and animals, both require the same food, that is, carbohydrates, fats, proteins, mineral salts and water. Plants and animals differ from each other, however, in the way they obtain their food. Most plants have the power of manufacturing food of complex composition such as carbohydrates, proteins, fats and oils from food materials of simple composition secured from the soil and the atmosphere. The foods thus manufactured are thereafter utilised for similar purposes and in similar ways as in animals. Animals, on the other hand, have to obtain their food ready-made, either directly from plants or indirectly through other animals which feed on plants. Furthermore, plants absorb food substances through the external surfaces of their bodies in liquid and gaseous forms, while animals take in food in the solid or liquid forms, usually through an aperture called the mouth.

**The Elements which Constitute the Food Substances of a Plant.** If we take a plant, wash it thoroughly, weigh it and then dry it by heating it to a high temperature of about 110°C., we will find by carefully weighing it again, that it has lost weight. The loss in weight varies between 50 to 90 per cent of the original weight and is due to the water driven away by heat. If the plant is burned by heating it to a higher temperature of about 600°C., and the gases given off together with the ash that remains are subjected to a chemical analysis it will be found that the elements of which the gases consist are carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus and chlorine, while the elements of which the ash consists are potassium, magnesium, calcium, iron, sodium, silicon, and sometimes traces of copper, boron, manganese, zinc, cobalt, iodine and so on. Of all the elements known to exist in nature as many as 40 have been found present in plant ash. If a large number of plants are chemically analysed it will be found that carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, chlorine, potassium, magnesium, calcium, iron, sodium and silicon are present in nearly every plant. These elements are called essential elements, the other elements found in traces only are called trace elements.

A plant must not only have all the essential elements and trace elements, but each element must be present in the proper proportion; an excess of any particular element is harmful to the plant.

It is not possible to chemically analyse a plant in a school laboratory but we can perform water culture experiments, as given under the heading 'Laboratory work' at the end of the chapter, to show the relative importance of the elements mentioned to the life of plants. By means of such experiments, plants, preferably seedlings, are grown in water containing a solution of known salts and the effects produced on their growth and development with regard to a variation in the salts in solution are noted. These experiments will enable you to determine the elements essential for the healthy growth of a plant, the form in which they are easily absorbed and the nutritive value of particular elements.

You already know that a plant absorbs its food substances through its roots and leaves. Water and dissolved mineral salts are absorbed by the roots while oxygen and carbon dioxide are absorbed from the atmosphere.

The elements used by the plant as its food substances are not present in the soil in the free state but in combination with each other in the form of salts. Water and various soluble salts are absorbed by the root-hairs in a state of solution. Certain salts which the plant requires are unavailable because they are insoluble in water. Some of these salts are made soluble by small amounts of acids, chiefly carbonic acid and acid potassium phosphate secreted by the roots.

Hydrogen is obtained by plants from water and from ammonium salts. It is an essential constituent of protoplasm, starch, proteins and cellulose.

Oxygen and carbon dioxide are absorbed from the atmosphere into the plant body through the stomata and lenticels. Oxygen is used by the plant for the purpose of respiration and is an essential constituent of protoplasm, starch, proteins and cellulose. Carbon dioxide is broken up into its constituent elements, the carbon part being used for the manufacture of carbohydrates while the oxygen is set free into the atmosphere. Other gases of the atmosphere that enter the plant are returned unused.

The element potassium is absorbed by plants chiefly in the form of sulphates, phosphates and chlorides. Clay soils are rich in this element and it is hardly ever added to such soils as a manure. It is a constituent of protoplasm, carbohydrates and proteins. If a plant is deprived of this element its leaves become yellow and mottled, its growth becomes checked and its storage organs become shrivelled.

Magnesium is absorbed by plants in all forms except in the form of chlorides. This element is a constituent of chlorophyll. In its absence the plant suffers from chlorosis or yellowing of leaves and its growth is checked.

Calcium is absorbed by plants in the form of sulphates, phosphates and nitrates. It is present as a constituent of cellulose. It neutralises acids which would otherwise have an adverse effect on the plant, and thus plays an important part in the absorption of minerals from the soil. An insufficient supply of this element in the soil is shown by the retarded growth of the plant and a distortion in the shape of young leaves.

Iron is absorbed by plants in a variety of compounds. It is essential for the formation of chlorophyll although it is not a constituent. In its absence the plant suffers from chlorosis.

Sodium is very widely distributed in nature, chiefly in the form of chlorides. Although it is absorbed by plants it does not play an important part in nutrition.

Sulphur is absorbed by plants in the form of sulphates. It is a constituent of protoplasm and utilised in the formation of proteins. It also plays a part in cell division and fruit development. Plants that lack sulphur suffer from chlorosis.

Phosphorus is absorbed by the plant in the form of phosphates. It is a constituent of protoplasm. Like sulphur, it is involved in all cell divisions and fruit development. Roots and other underground plant organs require phosphorus for their development. In the absence of phosphorus the leaves become abnormally dark.

Nitrogen is absorbed by the plant in the form of nitrates and nitrites. It is an essential constituent of protoplasm and utilised in the formation of proteins, chlorophyll and protoplasm. In the absence of this element, growth of the plant is limited, and the plant suffers from chlorosis.

Sodium is widely distributed in nature, chiefly as chlorides in which form it is absorbed by the plant. The plant thus obtains a supply of chlorine as well. Silica is absorbed in the form of silicates . None of these elements play a part in nutrition.

Copper, boron, manganese, zinc, cobalt and iodine, called trace elements, although found in plant ash in tiny amounts are yet indispensable for normal plant growth. Furthermore, in the absence of these elements, plants develop deficiency diseases. Their precise functions are not yet fully understood and it is only recently that many of the mysteries concerning them have been unravelled. Scientists are now of the opinion that trace elements are vital parts of enzymes, that is, catalysts which promote chemical reactions in all living things, without themselves being used up in the reaction.

**How a Plant Makes Use of the Elements it Absorbs.** The substances utilised by a living thing for its sustenance are called its food. It must be clearly understood that the food of both animals and plants is the same type of chemical compounds, which have a complex composition such as carbohydrates, proteins, fats and oils. The raw food materials of simple composition absorbed by the plant must not be regarded as food, but as food substances for it is out of these substances that the plant builds up or synthesises its food.

Before a plant utilises the food it has prepared it must change its food into soluble substances which can easily be transported and also pass through the walls of its cells. The process by which this is done is called digestion and is the opposite of synthesis, for it involves the breaking up of complex substances into simpler ones.

Both synthesis and digestion are accomplished by enzymes. Enzymes are catalysts produced by the activity of the protoplasm, which influence the rate of a chemical reaction either by accelerating or inhibiting the reaction, without themselves being used up in the reaction. Each enzyme is usually specific to a single chemical reaction, that is, it helps to transform one particular substance into another particular substance. Furthermore, the change they bring about is reversible. For example, the enzyme lipase, can change fatty acids and glycerine to fats and also change fats to fatty acids and glycerine.

By means of photosynthesis, of which you read in Book II, the cells in a leaf by virtue of their chloroplasts, are able to absorb sunlight (radiant energy) and transform it into chemical energy (potential energy) which is stored in complex foods called carbohydrates, synthesised from simple substances such as carbon dioxide and water. Carbohydrates are energy-giving foods. Sugar is the first carbohydrate formed by photosynthesis. As the concentration of sugar in the leaf reaches a certain critical level it is converted to starch by means of certain enzymes. At night the same enzymes convert the starch back to sugar, since starch is insoluble in water and cannot be transported from one part of the plant to another. The sugar is taken by food tubes, the phloem, to places where it is used for growth (i. e. transformed or assimilated into protoplasm) and respiration (i.e. liberation of energy) or to places where it is stored. Sugar is reconverted to starch in the storage organs.

Nitrates are the sources of nitrogen for the synthesis of proteins. The nitrates absorbed by the plant are first converted to nitrites, then to ammonium compounds which are thereafter converted to amino-acids and finally to proteins which form the basis of protoplasm. Excess proteins are stored in leaves, growing tissues and seeds. When proteins have to be transported they are converted by the help of enzymes to amino-acids. In this form they are readily assimilated by the plant into new protoplasm and used for the liberation of energy.

Fatty acids and glycerine are derived from carbohydrates and are changed by means of an enzyme to fats which are deposited as a reserve material in the protoplasm of plant cells in the form of droplets or globules. Fats that are liquid at moderate temperatures are called oils. When required by the plant, the same enzyme converts fats to fatty acids and glycerine, from which energy is liberated.

**Improvement of Soil.** As crops are removed from the soil year after year, the soil becomes impoverished in mineral salts. Manuring is done with a view to replenishing the minerals removed after harvesting. Chemical compounds prepared artificially in fertiliser factories are added to the soil in suitable proportions. This is called artificial manuring. In many cases natural manuring is practised by the rotation of crops. Farmyard manuring by which refuse derived from living things is added to the soil is also a common way of ensuring that plants obtain sufficient nourishment from the soil.

Agricultural operations such as ploughing, digging, forking, hoeing, rolling, raking and drainage improve the condition of the soil. Ploughing, digging and forking are done to loosen the soil and increase its porosity. By means of rolling, the air spaces in the soil become narrower and consequently the capillarity of the soil is increased. Raking is done to give a fine tilth for the growth of seedlings. If the soil is too wet, drainage operations are carried out to remove the excess water.

**How Animals Secure their Food.** We do not find much variation in the structure of plants with regard to the securing of their food substances since a plant is surrounded by its food substances. For the same reason plants remain fixed in the soil. The structure, movement and way of life of animals, however, are directly related to the securing of food.

Uni-cellular creatures such as the amoeba are without any definite form or specialised food-securing structures. Insects have mouth parts adapted for chewing or sucking their food. Among the birds we find a variety of beaks and feet adapted to the functions of capturing and breaking up their food for swallowing. The beak and feet of each kind of bird depends on the nature of its food and the mechanism used to capture it. The teeth of both herbivorous and carnivorous animals are adapted to ingestion or the taking in of food.

**How Animals Digest their Food.** The process of digestion is fundamentally the same in all living things, but in most animals a mechanical phase is included by which the food that is taken into the body is chewed, ground, churned and broken into smaller pieces. The chemical phase of digestion in animals is, in its essentials, of the same type as that already described for plants.

Among the lower forms of animals such as the protozoa, no distinct digestive system is developed.

The structures concerned with the intake of food (ingestion), the transformation of food of complex composition into simpler, soluble and diffusible substances (digestion) the intake of these substances by the interior of the body (absorption) and the expulsion of the residue of matter which could not be broken down into soluble forms by the enzymes (egestion), are regarded as belonging to the digestive system.

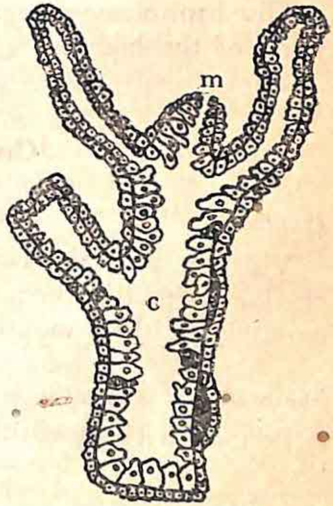
Among the lower forms of animals such as the protozoa no distinct digestive system is developed. The amoeba engulfs its food particles directly into the interior of its cell and then forms globular structures called food vacuoles. Enzymes are secreted into these vacuoles by the protoplasm which break up the solid food-particles preparatory to their absorption and final assimilation. Non-digestible remains are rejected. Paramecium, another protozoan, shows greater organisation in its digestive mechanism. In this animal we find an oral groove which terminates at an opening called the mouth. The mouth opens into a funnel-shaped cavity called the gullet which extends into the protoplasm.

Food passing down the gullet accumulates in a solid mass. When enough has collected, the food becomes surrounded by a clear liquid and breaks off as a food vacuole. Enzymes digest the food in the vacuole. While digestion is proceeding the vacuole traces a regular course through the protoplasm and finally reaches an opening which is situated just below the gullet called the anus. By the time it reaches this point only indigestible material remains in it. This material is now ejected out of the animal through the anus.

Apart from the protozoa there are two general types of digestive systems developed in the animal kingdom. In the flatworms and certain animals which fall into a group called the coelenterates we find a sac-like type of digestive system while in all other animals we find a tubular type of digestive system.

The sac-like system consists of a mouth which opens into a sac-like cavity called the gastrovascular cavity which is enclosed, throughout its entire length. Digestion is extracellular, that is, within the cavity, and intracellular, that is, within the cells lining the walls of the cavity. Indigestible materials are ejected through the mouth.

The tubular system consists of a mouth which opens out into a long tube called the alimentary canal which in turn terminates posteriorly with the anus. The alimentary



*Hydra.*
*c, gastrovascular cavity; m, mouth.*

canal is generally specialised along its length into a number of distinct regions in which digestion at various stages is carried out. These regions are usually the pharynx, oesophagus, stomach, small intestine and large intestine. In some animals some of these divisions are modified for special purposes. In birds, for example, the lower portion of the oesophagus is enlarged to form a crop in which swallowed food is stored while the posterior part of the stomach is modified as a gizzard for grinding the food. Certain portions of the alimentary canal are generally specialised for the absorption of digested food. Glands such as the liver and pancreas are connected to the canal, these supply various digestive juices that serve to break down the food still further. Indigestible material is ejected through the anus.

After food has been absorbed from the alimentary canal by the blood stream, it is distributed to all the cells of the animal's body where it is assimilated into protoplasm or oxidised to release energy. Surplus food is stored in various parts of the body.

## CHAPTER ACTIVITIES

*Outdoors*

Visit the animal section of the museum. Try to guess the kind of food of the animals that are displayed by looking carefully at their mouths.

*For your wall newspaper*

Prepare a chart entitled 'Animal food-securing adaptations'.

*Note-book exercises*

1. Study the tables given in Nos. 1 and 2 under

'Laboratory work' after they have been compiled. Write explanatory accounts of them.

2. Compare the digestive systems of the animals given in No. 3 under 'Laboratory work'. Do this with the help of books in your science library.

*Laboratory work*

1. Obtain pea or bean seeds. Select three seeds of the same kind that are as nearly as possible of the same weight. Record the weight of each seed. Take one of the seeds, cut it up into tiny bits and place it in a crucible. Place the crucible in a hot-air oven for a few hours. Next allow the crucible to cool and find the weight of the seed again. Replace the crucible in the oven for a further period and then weigh it again. Continue to repeat heating the seed until there is no further loss in weight. When the seed has had all the water driven off by heating, its weight will be the same for successive heatings. Find the weight of water originally present in the seed by subtracting the final weight of the seed after its last heating from its original weight and from this, calculate the percentage dry weight of the seed. Next heat the crucible and its contents over the flame of a bunsen burner until only the ash of the seed remains. Allow the crucible to cool and then weigh it. Continue to repeat the heating of the ash until there is no further loss in weight. Calculate the percentage weight of the ash from the final weight of the ash.

Germinate one of the remaining seeds in sand and the other in garden soil. When the seedlings have developed sufficiently, carefully remove them from their respective soils. Wash each with distilled water and dry them by means of blotting paper. Find the percentage dry weight of each seedling and the percentage weight of the ash of each seedling as you did in case of the seed. Enter your results in a table such as that given below.

| | *Weight before heating* | *Dry weight* | *Percentage dry weight* | *Weight of ash* | *Percentage weight of ash* |
|---|---|---|---|---|---|
| Seed | | | | | |
| Seedling grown in sand | | | | | |
| Seedling grown in garden soil | | | | | |

2. We can see the relative importance of the elements mentioned in the text, to the life of plants by performing water-culture experiments.

A solution which contains all the elements needed by a plant in the right proportions is called a normal solution. Prepare a normal solution from the following prescription :

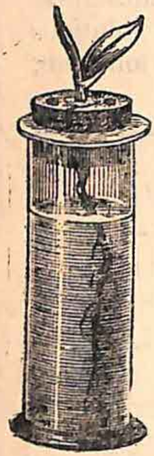
| | |
|---|---|
| Distilled water | 1 litre |
| Potassium nitrate | 1 gm. |
| Sodium chloride | ·5 gm. |
| Calcium phosphate | ·5 gm. |
| Magnesium sulphate | ·5 gm. |
| Calcium sulphate | ·5 gm. |
| Iron chloride | a few drops |

Boil the above solution for about half an hour. After boiling the solution some of the water would have evaporated. Add more distilled water to make up a complete litre.

To find the extent to which plant growth and development depends on individual elements as food substances it will be necessary to prepare a series of solutions omitting one element at a time as indicated in the following table :

| *Element omitted* | *Substitution of salts in the normal solution* |
|---|---|
| Potassium | Replace potassium nitrate by sodium nitrate |
| Magnesium | ,, magnesium sulphate by sodium sulphate |
| Sodium | ,, sodium chloride by potassium chloride |
| Calcium | ,, calcium phosphate and calcium sulphate by magnesium sulphate and magnesium phosphate |
| Nitrogen | ,, sodium nitrate by sodium sulphate |
| Chlorine | ,, sodium chloride by sodium sulphate |
| Sulphur | ,, calcium sulphate and magnesium sulphate by calcium phosphate and magnesium phosphate |
| Phosphorus | ,, Calcium phosphate by calcium nitrate |
| Iron | Omit iron chloride |

Obtain ten jars of the same size and shape and clean them thoroughly by rinsing them successively with tap water, dilute nitric acid and distilled water. Fit each vessel with a cork that has been split as shown in the accompanying illustration.



*A seedling growing in a culture solution.*

Germinate the seeds of a pea of bean plant on damp sawdust and when the seedlings have developed sufficiently wash them in distilled water.

Fill three-fourths of each jar with the given culture liquid and introduce a seedling in it so that its roots are in the solution. Number the jar and pack the space around the seedling with sterilised cotton-wool. Cover the jars with black paper so as to keep the roots in the dark. Place the jars on a window-sill which receives a good supply of sunlight. Observe the growth and development of each seedling over a period of several weeks as compared with the growth of the seedling in the normal solution. Enter your results in a table as the one below :

| *No. of jar* | *Peculiarity of culture solution* | *Changes observed* |
|---|---|---|
| | | |

3. Dissect the following animals and examine their alimentary canals : earthworm, cockroach, toad, fish, pigeon and rabbit. Make labelled drawings of the alimentary canal of each animal.

*At home*

1. Write an account of how the structure, movement and way of life of any three animals are related to securing food. Use the account for a class symposium on 'Animal food securing adaptations'.

2. A useful mnemonic for helping you to remember the elements found in nearly every plant is

NaSiCl CaFe
Mg. K. N. CHOPS.

Attempt to construct other such mnemonics to help you remember other lists of elements given in this chapter.

## CHAPTER XII

## THE FROG

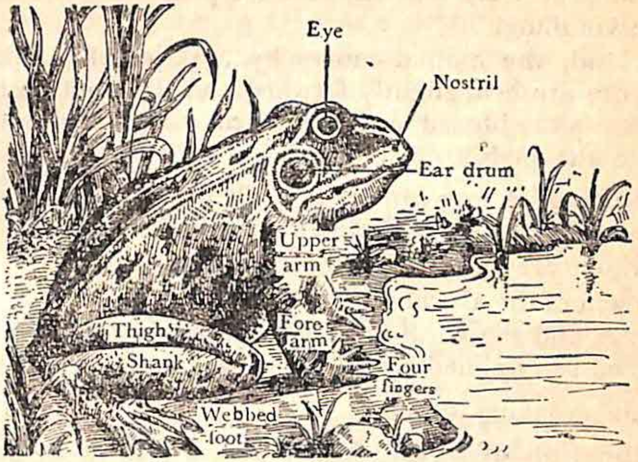
THE frog is a representative of the amphibia. The animals in this group undergo a transformation from an existence in water to an existence on land and thereafter lead a double life, one part of which is spent in the water and the other on land. The amphibia occupy a position midway between the lower vertebrates and the higher vertebrates.

The frog spends most of the year lying fast asleep or hibernating, in the mud at the bottom of the pond. In its body there is a store of food which is slowly used up as the months go by. When the monsoon arrives, it is up and about from the very first downpour. Its croaking together with that of its near relations, the toads and the bull frogs, can be heard clearly on monsoon nights.

The frog lives in and around ponds and is also frequently seen in damp fields, waste land and in gardens. Gardeners are pleased to see frogs in their garden for they know that this creature is their friend since it feeds on such pests as green flies, slugs and many kinds of insect larvae that are harmful to plants.

We shall now study in a rather detailed manner the external features, the internal structure and the various functions of the organs of the frog. In doing so, we shall give some general ideas about these various points, so that this chapter may serve as a preparation and introduction to the study of the human body, which we shall take up in the following chapter.

**External Features.** The head of the frog is continuous with its trunk, there being no neck to separate them. The animal has four limbs, the two in front far shorter than the two behind. The forelimbs are usually held in an upright position and support the anterior part of the body. Each



*The frog.*

fore limb consists of an upper arm, a forearm and a hand with four short fingers. In the case of a male frog there is a small pad at the base of the first finger which becomes very swollen in the mating season. The hind limbs are folded into a Z-shape when the animal is at rest and supports the posterior portion of the body. Each hind limb consists of an upper leg, a lower leg and a foot with five long toes joined together by a membranous web. The skin is smooth, moist, slimy and loosely attached to the flesh. On the head are two large prominent eyes. The upper eyelid is almost immovable, while the lower eyelid is absent. There is, however, a transparent eyelid which can be swept freely across the eye for cleansing purposes. Just behind each eye is a tightly stretched circular patch of skin called the eardrum or tympanic membrane. In front of the eyes are two small openings called nostrils. The mouth is wide and air-tight when closed.

**Movement.** The absence of a neck makes the frog 'streamlined' and it is thus able to pass rapidly through the water.

Its webbed feet are efficient oars for propelling the animal when swimming.

On land, the animal moves by a series of jumps, the fore limbs are held slightly forward and the hind limbs are suddenly straightened out backwards to give a powerful push to the body.

**Croaking.** A frog can croak while under water as well as on land. It passes air back and forth from its lungs into vocal sacs which are situated in the cavity of the mouth. The movement of the air causes the vocal cords, situated between the lungs and the vocal sacs, to vibrate and the sound thus produced is amplified by the vocal sacs so that we hear the familiar croaking sound.

**Coloration of Skin.** You must have noticed that the colour of the frog's skin blends with that of its surroundings. This is because the animal can, to a certain extent, change its colour to match its surroundings. By doing this it camouflages itself from its natural enemies such as snakes and water birds.

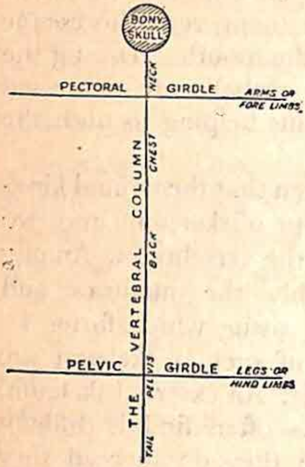
*How the frog gets its prey.*

**Feeding.** The frog is a carnivorous animal. Its food includes living animals, such as slugs, worms, insects, spiders, fish and tadpoles. The mouth of the frog contains a protrusible tongue. When the tongue is not in use it is folded back with its tip lying down the throat. The tip of the tongue is forked and sticky. When the frog spies an insect moving in its immediate vicinity it darts its tongue out quickly, captures its prey and then flicks its tongue back into its mouth. Around the upper jaw is a row of teeth and on the roof of the mouth are two separate patches of teeth. The teeth point inwards and serve to prevent the escape of any animal that is imprisoned in the mouth. During the process of swallowing its prey the eyeballs are depressed and bulge into the mouth cavity, thus helping to push the food down the throat.

**The Skeletal System.** We have seen that the animal kingdom is classified according to the type of skeleton, into two main groups, the invertebrates and the vertebrates. Among many of the invertebrates, notably the molluscs and arthropods there exists a stiffening tissue which forms an external skeleton. The functions of such a skeleton are chiefly that of protection and support. An external skeleton, however, hinders growth. Molluscs often find it difficult to get out of their shell and when they do succeed they remain defenceless until a new shell grows and hardens. Some arthropods cast off their external skeleton several times during their period of growth and some also during the period of their adult live . As in the case of molluscs, skin casting is a difficult and dangerous process.

All vertebrates have an internal skeleton while some have an external skeleton as well. Among fishes the external skeleton takes the form of scales while among turtles and tortoises it is seen in the form of shields.

The internal skeleton of all vertebrates is constructed on the same general plan. It consists of a main axis along which lie the skull, backbone, ribs and breastbone. At the upper end of the axis is the pectoral girdle to which the fore limbs are attached, while at the lower end is the pelvic girdle to which the hind limbs are attached. Although an internal skeleton does not give such complete protection to the body as an external one, yet this disadvantage is to a great extent offset by the fact that it does not hinder growth and is better adapted to allow free movements of the various parts of the body.



*General scheme of vertebrate skeleton.*

The skeleton of the frog is composed of bone and cartilage. Its functions in general are to provide a framework for the attachment and support of most of the muscles of the body and to afford protection of the main organs of the body.

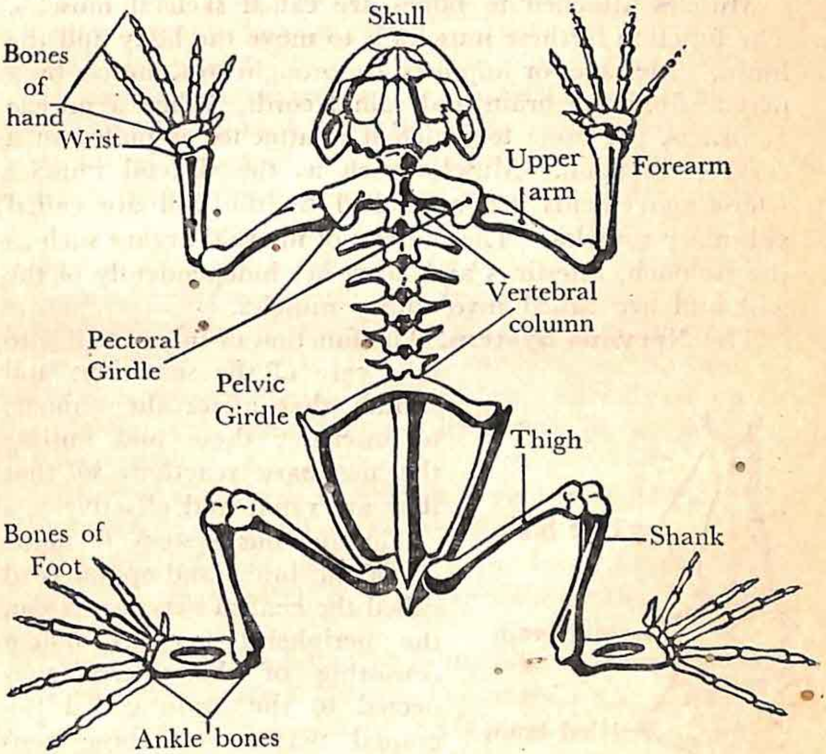
The main parts of the skeleton are the skull, the vertebral column, the girdles and the limb bones. These parts are kept together by tough fibrous bands of connective tissue called ligaments, which run from one bone to the other and hold each one in its place. Distinct breaks where the bones meet, called movable joints, allow body movements. At places where one bone touches another there are pads of cartilage to reduce friction between the bones. A lubricating fluid called synovial fluid produced in these regions further helps to reduce friction by lubricating the end surfaces of the bones. At certain places bones come together in such a way that no movement is possible. These joints are called immovable joints.

The skull is broad, flattened and made up of numerous bones, all of which are immovably fixed together except the lower jaw which has a movable joint which helps the frog to open and close its mouth.

The vertebral column or backbone consists of ten parts. The first nine parts are distinct bones called vertebrae while the tenth is a slender, elongated rod called the urostyle. The first vertebra is connected to the skull while the urostyle bears the pelvic girdle. The function of the vertebral column is to protect the spinal cord which runs through its entire length.

The pectoral girdle supports the two fore limbs and attaches them to the vertebral column. It also protects the lungs and heart. The pelvic girdle supports the two hind limbs and attaches them to the vertebral column.

The bones of the fore limb consist of a single upper arm bone which is fitted to the forearm bone which actually consists of two separately fused bones. At the lower end of



*Skeleton of the frog.*

the forearm are a number of wrist bones which are connected to the bones of the fingers.

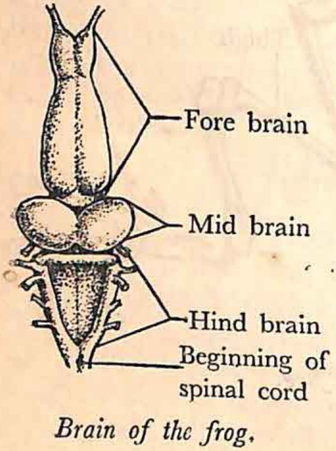
The bones of the hind limbs consist of a single thigh bone which is fitted to the shank bone which actually consists of two separately fused bones. Then follows a number of ankle bones which are connected to the bones of the toes.

**The Muscular System.** The movements of an animal's bones and organs are brought about by the action of muscles. Muscles are made up of cells in the shape of fibres which contract or make themselves shorter on stimulation.

Muscles attached to bones are called skeletal muscles. The function of these muscles is to move the body and the limbs. Messages or impulses are brought to a muscle by a nerve from the brain and spinal cord. When a muscle contracts, the bone to which it is attached is pulled in a certain direction. Muscles such as the skeletal muscles whose movements are controlled by the will are called voluntary muscles. The muscles of internal organs such as the stomach, intestines and heart act independently of the will and are called involuntary muscles.

**The Nervous System.** The function of this system is to take care of the sensations and stimuli that affect the animal; to interpret these and initiate the necessary reactions so that they are rapid and effective.

The nervous system is made up of the brain and spinal cord called the central nervous system, the peripheral nervous system consisting of the nerves connected to the brain called the cranial nerves and those connected to the spinal cord called the spinal nerves, and the autonomic nervous system consisting



*Brain of the frog.*

of a set of nerves which control the involuntary reactions of the body.

The brain is contained in the skull while the spinal cord is contained in the vertebral column. The work of both these parts of the central nervous system is to receive sensations and stimuli from the rest of the body and to control the functions of the various parts of the body so as to promote the welfare of the animal.

The peripheral nervous system is made up of the cranial and spinal nerves. These nerves either bring messages to the central nervous system (sensory nerves) or carry away messages from it (motor nerves). There are ten pairs of cranial nerves and ten pairs of spinal nerves in the frog.

The autonomic nervous system consists of a pair of thin whitish nerve trunks that run down the back of the animal's body on either side of the vertebral column with branches running out to those organs that are controlled automatically. This system helps to control the action of certain organs such as the heart, and the organs of the digestive, respiratory, excretory and reproductive systems.

**Sense Organs.** The sense organs are part of the nervous system and their work is to receive stimulations from either without or within the body and transmit the stimuli on to the sensory nerves thus keeping the animal in contact with the surroundings.

The sense of sight is located in a pair of well-developed eyes which are specialised for responding to light.

The sense of smell is located in the nasal cavity which contains a small patch of tissue containing the organs of smell.

The sense of touch is located in the skin. The sense organs of touch are sensitive to contact. Pain is the result of extreme stimulation of these organs. In the skin are also organs which are sensitive to changes of pressure and temperature.

The sense of taste is located in the tongue. Here there are taste buds which are connected to the free nerve terminations so that the sensation is handled more effectively.

The sense of hearing is located in the ear. Sound vibrations are picked up by the tympanic membrane, then transferred through the ear bones of the middle ear to the fluid in the inner ear. Nerve endings are found in the inner ear and these nerves transform the vibrations of different rates into impulses which proceed to the brain where they give the animal impressions of sounds of different tones.

The sense of balance is also located in the ear. There are three semi-circular canals so arranged that each is at right angles to the other two. These canals are responsible, in a way that will be described later, for the proper muscle co-ordination which is required to maintain balance.

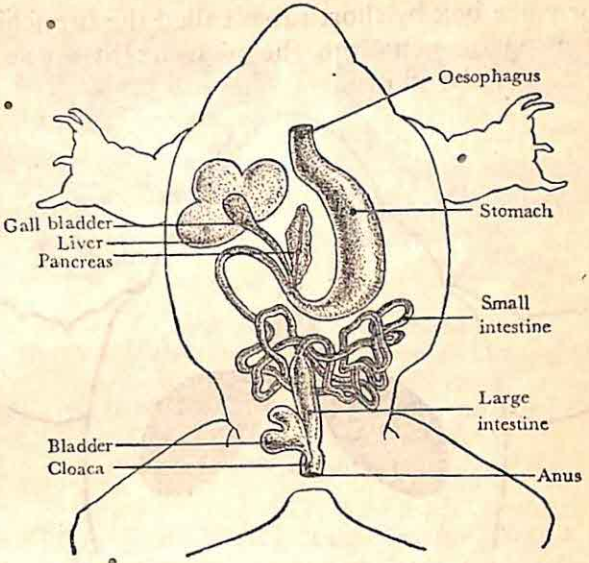
**The Digestive System.** This system begins with the mouth which leads through the short oesophagus to the wide crescent-shaped stomach. The stomach in turn leads to the much coiled small intestine whose lower end opens into the wide, large intestine. The posterior portion of the large intestine widens into a cavity called the cloaca which communicates with the outside by way of the anus.

Two important glands, the liver and the pancreas are in close association with the digestive system. The liver manufactures bile which is collected by fine tubes and conveyed for storage to the gall bladder. The bile is sent from the gall bladder, when required, to the small intestine to help in the digestion of food.

The pancreas manufactures pancreatic juice and supplies it by means of tubes to the small intestine to help in the digestion of food.

The function of the digestive system is to break down the food and prepare it for absorption into the circulatory system so that it may be distributed to all parts of the body.

Digestion is accomplished by muscular contraction of the walls of the alimentary canal which not only serves to break



*Digestive system of the frog.*

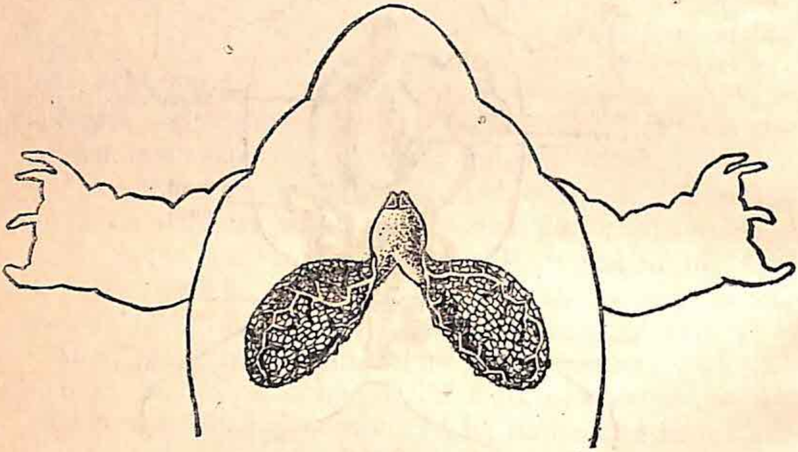
up the food into finer particles but also to push the food along the canal. Digestion is also accompanied by the action of various enzymes in the digestive juices secreted by the liver, pancreas and walls of the stomach and small intestine.

Digested materials are absorbed through the walls of the small intestine.

Indigestible materials are passed to the large intestine and thence to the cloaca from where they are finally eliminated as wastes through the anus.

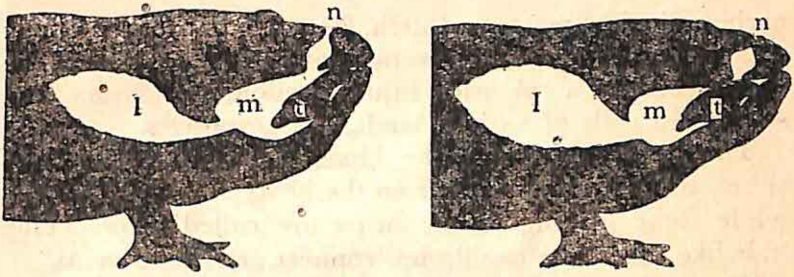
**The Respiratory System.** The organs comprising the respiratory system are the lungs, the mucus membrane of the mouth and skin.

Two small oval, greyish sacs, the lungs, are situated in the anterior part of the body-cavity. They open into the larynx or voice box by short tubes called the bronchi. The larynx, in turn, opens into the pharynx by means of an opening called the glottis.



*Lungs of the frog.*

Since there is no diaphragm in the frog the animal cannot inhale or exhale air steadily and continuously without closing its nostrils, as we are able to do. Furthermore, the frog has no tracheae. When the frog inhales air it lowers the floor of its mouth and since the mouth and glottis are closed at this moment air flows in through the open nostrils. The frog then raises the floor of its mouth and since the nostrils are now closed, whereas the glottis is open, air is forced into the lungs where respiratory exhange of gases takes place. Air is forced out of the lungs and into the mouth by the contraction of the abdominal muscles which forces certain abdominal organs against the lungs and also by the recoil of the lung walls which are elastic. The frog exhales air by raising the floor of its mouth and, since the glottis and the mouth are closed at this moment, air passes out through the nostrils.



*To show how the frog inhales.*
*Left: the floor of the mouth is lowered and air rushes in through the nostrils to fill the mouth cavity.*
*Right: the floor of the mouth is raised, the nostrils are closed and air is thus forced into the lungs.*
*l, lungs; m, mouth; n, nostrils; t, tongue.*

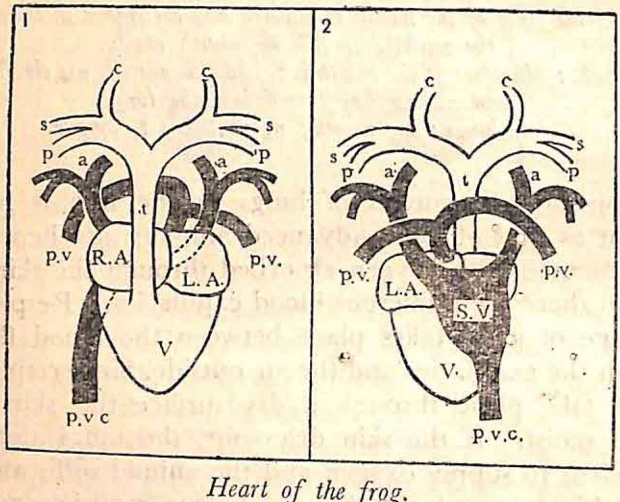
Respiration by means of lungs in the frog is not as efficient as that of more advanced animals and hence it is supplemented with oxygen absorbed through the skin. In the skin there are numerous blood capillaries. Respiratory exchange of gases takes place between the blood flowing through the capillaries and the air outside. Since respiration cannot take place through a dry surface the skin must remain moist. If the skin dries out, the lungs alone are insufficient to supply oxygen and the animal suffocates.

Breathing through the skin can be accomplished on land as well as when the animal is submerged in the water. The oxygen obtained in this way, however, is not enough to supply the energy requirements of the animal and if it cannot get to the surface to breathe by its lungs it will drown. On the other hand, when the animal hibernates, its energy requirements are low. At this period of its life it breathes chiefly through its skin.

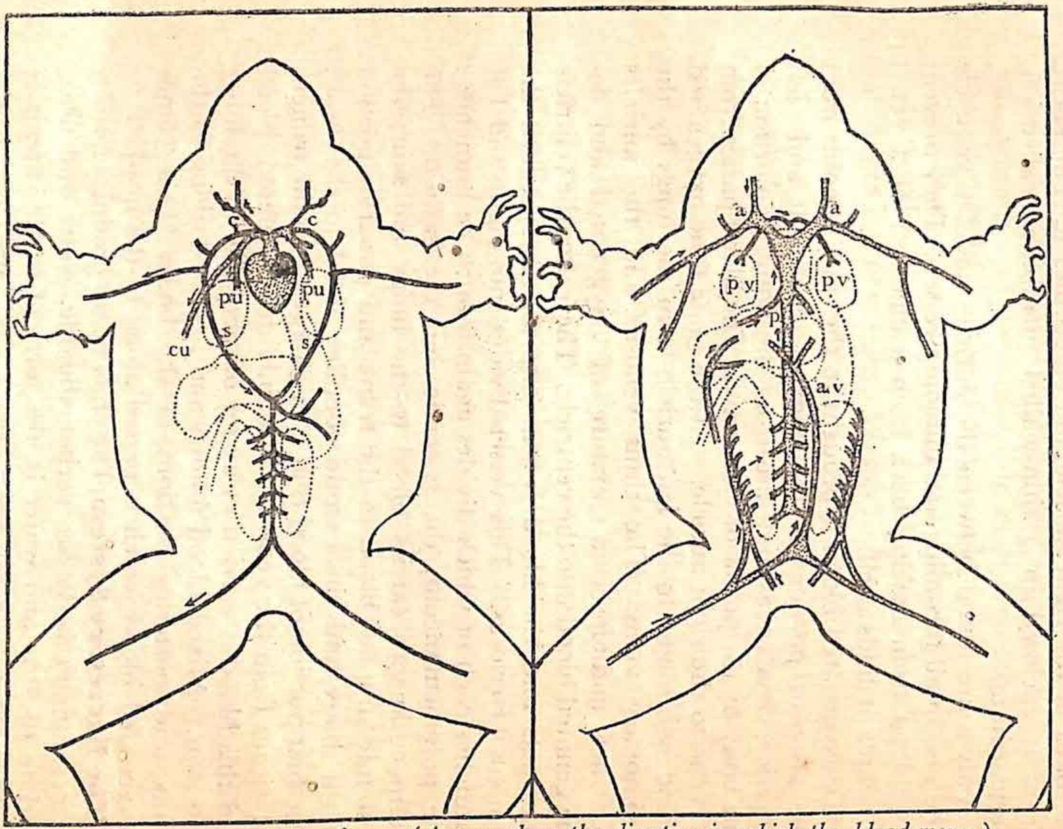
**The Circulatory System.** The system is completely closed and conveys a reddish fluid, the blood, which mainly transports food, oxygen and various waste products such as carbon dioxide, water and urea, from one part of the body to another. As in more advanced animals the blood of the frog consists of a colourless liquid portion, the plasma, and suspended cells of various kinds, the corpuscles.

The heart distributes the blood through a system of tubes, those leading away from the heart are called arteries while those leading to the heart are called veins. Fine hair-like tubes, the capillaries, connect arteries to veins.

The heart is made up of three muscular chambers, the two upper chambers separated from each other by a partition are called auricles while the lower chamber is called the ventricle. A thin walled sac called the sinus venosus, formed by the convergence of the right and left anterior



*Heart of the frog.*
1. *Front view.* 2. *Back view.*
*L.A., left auricle; R.A., right auricle; S.V., sinus venosus; V, ventricle.*
*a, anterior vena cava; c, carotid; p, pulmocutaneous; p.v., pulmonary vein; p.v.c., posterior vena cava; s, systemic; t, truncus arteriosus.*



*Circulatory system of the frog. (Arrows show the direction in which the blood moves.)*
1. *Principal arteries: c, carotid; cu., cutaneous; pu., pulmonary; s, systemic.* 2. *Principal veins: a, anterior vena cava; a.v., abdominal vein; p, posterior vena cava; p.v., pulmonary vein.*

vena cava and also the posterior vena cava, is attached to the back of the right auricle and opens into it. The entire heart is enclosed in a thin-walled membrane called the pericardium.

Valves are found between the auricles and the ventricle and also in all incoming and outgoing vessels. They prevent the blood from flowing back from a chamber or a vessel in which it finds itself.

Deoxygenated blood is brought to the sinus venosus from the anterior portions of the body by the right and left anterior vena cavas and also from the posterior portion of the body by the posterior vana cava. The blood passes from this sac to the right auricle. At the same time oxygenated blood is brought to the left auricle from the lungs by the pulmonary veins. The sinus venosus and the auricles contract and force a mixture of oxygenated and deoxygenated blood into the ventricle. Thereafter the ventricle contracts and the blood is sent into an artery called the truncus arteriosus. This vessel divides into right and left branches each of which divides again into three branches : the pulmocutaneous, the systemic and the carotid. The pulmocutaneous carries blood to the lungs and skin; the systemic supplies blood to the trunk and posterior portion of the body and the carotid supplies blood to the head. The first portion of blood that is discharged into the truncus arteriosus from the ventricle is mainly deoxygenated blood and this blood is carried away for oxygenation to the lungs and skin. Mixed blood follows and is passed along to the trunk and posterior portions of the body. Last comes oxygenated blood which is passed along to the head.

**The Excretory System.** The chief waste products formed in an animal's body are carbon dioxide, water and urea. Carbon dioxide and water in the form of water vapour is got rid of by the respiratory organs while urea which is a soluble nitrogenous substance is got rid of as urine by means of the kidneys which are the chief excretory organs.

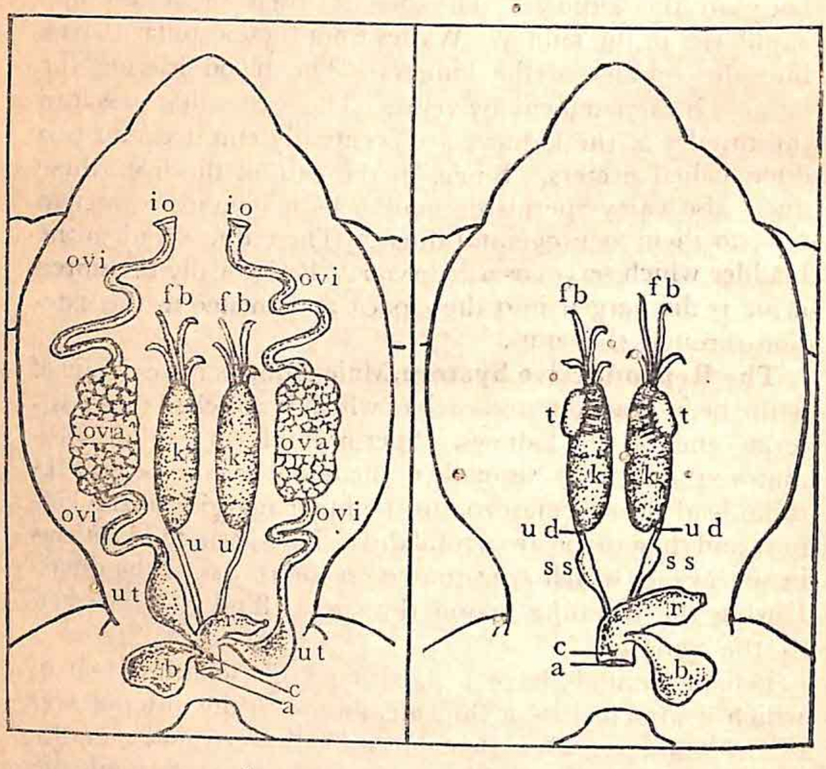
The kidneys are two flattened, elongated, reddish-brown glands situated in the middle of the body cavity just beneath and on either side of the vertebral column. They consist of a mass of tiny tubules.

Two separate arteries bring the excretory wastes of the body to the kidneys. The blood vessels break up into capillaries in the kidneys. Wastes from these capillaries pass into the tubules of the kidneys. The blood leaving the kidneys is carried away by veins. The wastes that pass into the tubules of the kidneys are eventually emptied into two ducts called ureters. Since, in the case of the frog, these ducts also carry sperms or male cells it is more correct to refer to them as urogenital ducts. These ducts lead to the bladder which serves as a reservoir. Periodically the stored urine is discharged into the cloaca and thence to the exterior through the anus.

**The Reproductive System.** Male animals have a pair of white bean-shaped testes, each of which is attached to the anterior end of the kidneys. Sperm fluid containing spermatozoa (male cells ) is made in the testes. A number of thin tubes lead the spermatozoa to the inner margins of the kidneys and then to the urogenital ducts. The sperm fluid collects in sperm sacs which are situated on the course of the ducts. During the breeding season the sperm fluid is discharged to the exterior.

Female animals have a pair of sac-like ovaries each of which is attached by a thin membrane to the anterior end of the kidneys. Ova (female egg cells) are made in the ovaries. When these cells are ripe they break through the walls of the ovaries and enter the body cavity from where they migrate to, and enter, the upper open end of a pair of oviducts each of which is situated under the lungs on either side of the oesophagus. Having entered these tubes the ova are carried down to an enlarged chamber called the uterus. During their journey down the tubes they become coated with slime. At the proper time they are passed from the uterus to the cloaca and then discharged to the exterior.

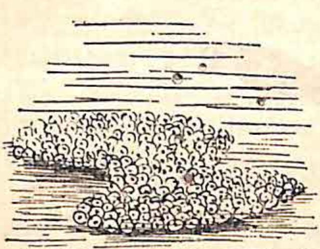
Both male and female animals have yellowish finger-like fat bodies attached to their reproductive glands. These



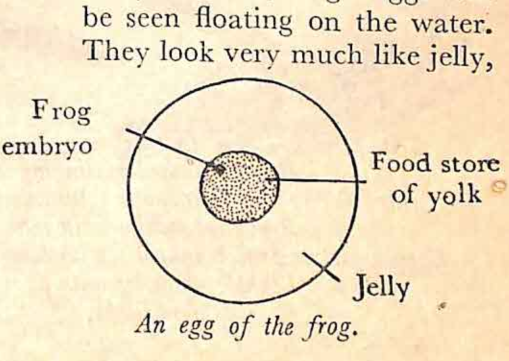
*The excretory and reproductive systems of the frog.*
*1. Female frog: a, anus; b, bladder; c, cloaca; f.b., fat bodies; i.o., internal opening of oviduct; k, kidney; ova., ovary; ovi., oviduct; r, rectum; u, ureter; ut., uterus.*
*2. Male frog: a, anus; b, bladder; c, cloaca; f.b., fat bodies; k, kidney; r, rectum; s.s., sperm sacs; t, testes; u.d., urogenital duct.*

bodies contain reserves of food which serve not only the reproductive glands, but also the animal during its period of hibernation. As the eggs are laid by the female, the male sheds sperms over them. Fertilisation now takes place. It must be noted that fertilisation takes place outside the female animal and that water is necessary for the sperms to swim to the egg. Having shed the sperms the male goes his separate way. The female also shows no interest in the eggs. The eggs called spawn may number anything from one thousand to two thousand.

**Development of a Frog from a Fertilised Egg.** A fertilised egg is coloured black above while the rest of it is white. In the centre of the egg is a tiny black ball. Within this ball lies the embryo embedded in yolk. The yolk serves as food for the embryo as it develops. The rest of the egg is a jelly and consists of albumen and water. This jelly has no nutritive value but serves to protect the embryo from enemies, as it makes the egg difficult to swallow. It also prevents overcrowding.

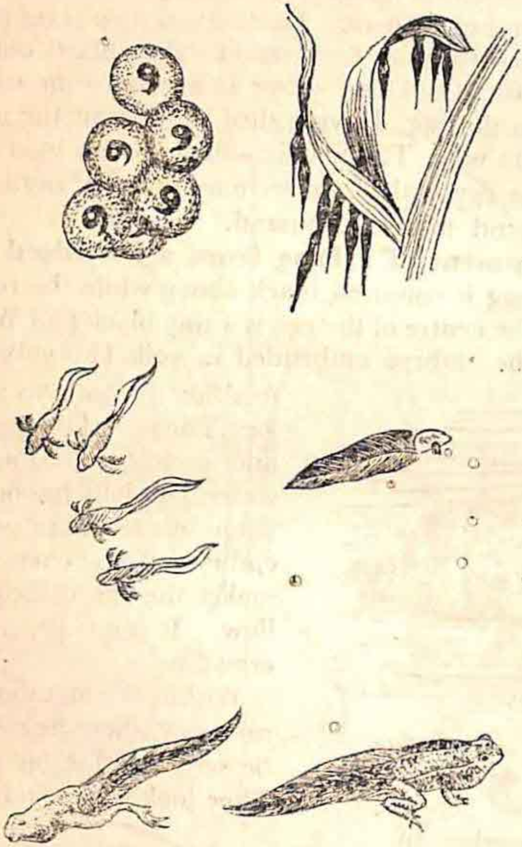

*Frog's eggs floating on the water.*

Within the first month of the rainy weather, frogs' eggs will be seen floating on the water. They look very much like jelly, and a number of them are grouped together. After a few days little black tadpoles wriggle out of the eggs and cling to water-weeds.



*An egg of the frog.*

A tadpole has a large oval head and a long, flattened tail. For the first few days it remains attached to the remains of

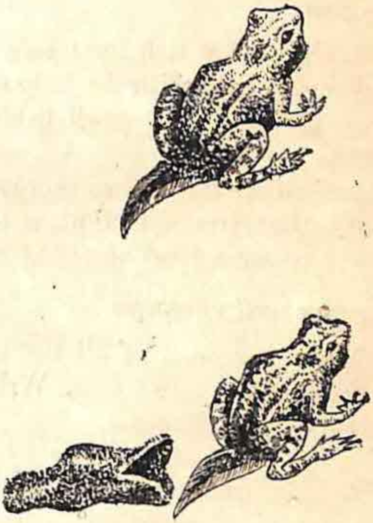


*Top picture Left : tadpoles wriggling out of their eggs.*
*Right : tadpoles clinging to water-weed.*
*Centre picture Left : tadpoles with external gills.*
*Right : tadpoles with internal gills.*
*Bottom picture Left : tadpoles with hind limbs.*
*Right : tadpoles with hind limbs and fore limbs.*

the yolk by a sucker-like cement gland on the under-surface of its head. At this time it feeds on the remains of the yolk and breathes through its skin. Thereafter it swims to a water-plant to which it attaches itself for a few days. It now develops a pair of horny jaws, a pair of beady eyes and a pair of simple pits on the side of its head with which it hears. From each side of its neck grow two thread-like external gills which contain capillaries. Later on a third pair of external gills grow out of the neck. The animal respires through these gills as well as through its skin. At this time it feeds on vegetable matter.

During the next few weeks the tadpole develops rapidly. A long coiled gut can be seen through the body wall. The gills wither and fall off. Four gills, situated on either side of its neck develop internally. The tadpole uses these gills like a fish and respires oxygen dissolved in the water.

When the tadpole is about eight weeks old it changes rather abruptly into a small frog. This change is called metamorphosis. Hind legs first push their way out of the animal's body, the horny jaws are shed and a mouth develops. The internal gills wither and lungs develop. The front legs push their way out of the body. Now we do not call the little creature a tadpole any



*Top picture : a baby frog.*
*Lower picture : a young frog with its skin cast.*

longer for it has grown into a baby frog.

The baby frog shows a liking for the land and will spend a little time every day on the side of the tank. The lungs that are new inside its body help the frog to breathe on land as we do. The animal becomes carnivorous and eats insects, worms and even tadpoles.

As is grows its coat gets tight, splits and falls of. Its new coat looks smart and has the same colour as the plants growing around the tank. The young frog's tail becomes shorter as it is being absorbed and soon it looks just like its parents.

## CHAPTER ACTIVITIES

### *Outdoors*

1. Keep a watch for frog's eggs and tadpoles. You can collect the eggs with the help of a tin-can tied to the end of a long pole. Use a small fishing-net to catch tadpoles and frogs.

2. During the winter months, carefully turn up any large stone that you may find in the compound. You may be lucky to see a toad enjoying its winter sleep.

### *For your wall newspaper*

Make a record of all the changes that happen when a tadpole grows into a frog. Write the date and draw a picture of each new change.

### *Note-book exercises*

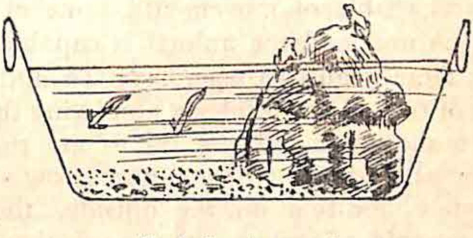
1. Make a comparison of the frog and toad.

2. Describe in detail all the changes you observe during the development of a frog from an egg. (*See* Laboratory work, No. 2.)

*Laboratory work*

1. Examine dissected specimens of frogs that have their various systems exposed.

2. Find a metal vessel such as an old tub, which does not leak. Fill it with water from the tank. Now select a few large stones that are covered with moss, put them inside the tub so that they are just above the water. See that there are a few water-weeds in the tub. When you find any frogs' eggs or tadpoles put them into your little 'tank'. You will find that when your tadpoles are beginning to change into frogs they will like a piece of meat. Chop some meat into very tiny pieces and give it to them.



*Tadpoles in a tub.*

*At home*

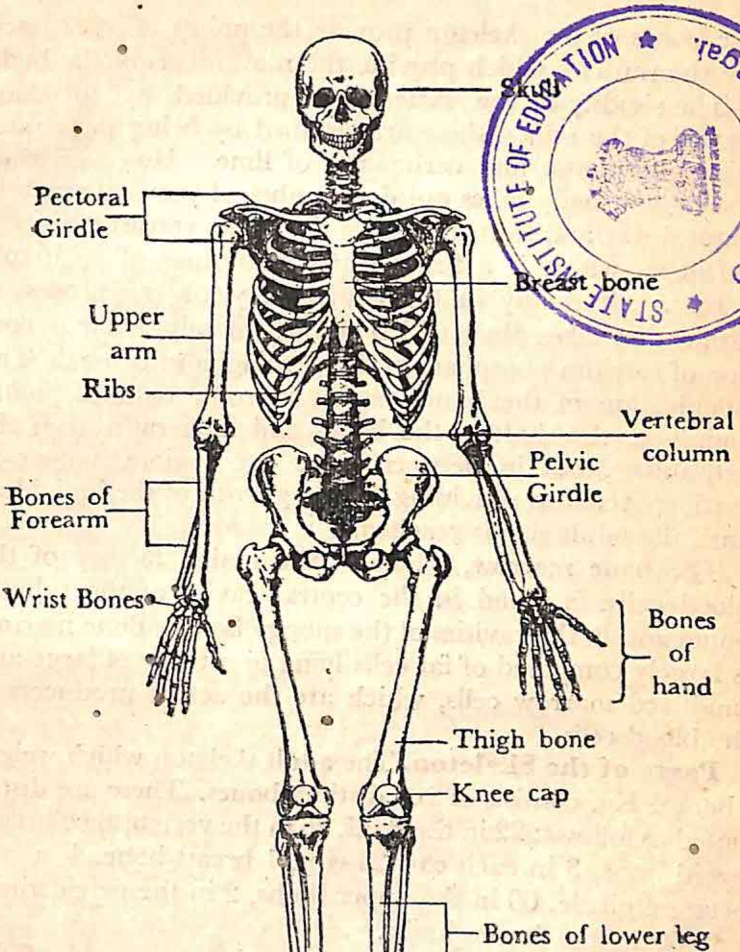
Make an examination of the structure and way of life of a frog. Note the following : (*a*) general structure; (*b*) body movements on land and in water; (*c*) breathing movements; (*d*) change of colour when placed against different backgrounds (*n.b.* each change takes place after several hours) and (*e*) method of feeding (*n.b.* live flies must be used).

# CHAPTER XIII

# HOW WE MOVE

ANIMALS, including man, have a definite shape, which however gradually develops and increases in size during the period of growth. On the other hand, the various parts of the body are capable of movements, some of them of a complicated nature, and the animal is capable of moving as a whole. How is all this possible? To understand the implications of this , just consider a non-living thing such as a house or a mountain. These things are rigid, have a definite shape and size, but they cannot grow and develop except by mere addition on the outside, their various parts are incapable of movements nor can they move as a whole. In the case of a machine, for example, its various parts are capable of movement, it may even be able to move as a whole, but all these movements will always be according to the same, unalterable pattern, without any variation or any spontaneity; and certainly it is unable to grow and develop, and so to increse its power, it is what we call a mere mechanical contrivance, howeve. intricate and efficient it may be, but it is not a living beingr

**The Human Skeleton.** The human body has a definite shape, and we find no difficulty in distinguishing man from any other type of animal. Having a definite shape implies that the human body must have a rigid framework to support its various parts. This rigid framework is the skeleton which consists of a large number of bones, connected and jointed in such a way as to provide the required support for the various parts of the body and to join and build them up so as to realise the distinctive shape of the human body.At the same time the different parts of the skeleton are so arranged as to provide protection for the more delicate organs of the body. Last, but not least,



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*The human skeleton (front view).*

the bones of the skeleton provide the points of attachment for the muscles which provide the movements of the body.

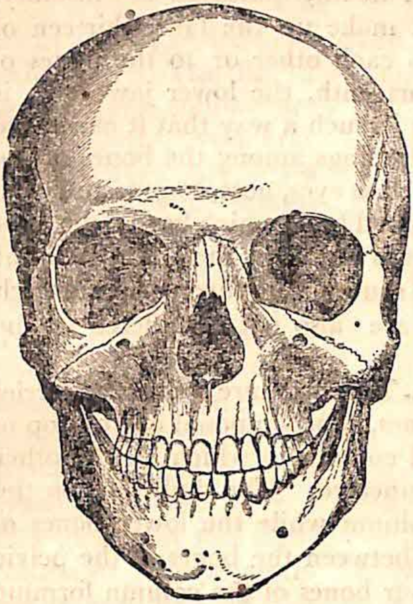
The rigidity of the skeleton is provided by the hard tissues of the bones, these are petrified by being penetrated with phosphates and carbonates of lime. However, since the human body takes quite a number of years to reach its natural size and stature, at first the bones consist mainly of cartilage, which is a firm, elastic substance of gelatinous nature. Gradually in the course of years the process of ossification takes place which consists mainly in the deposition of calcium phosphate in the cartilaginous tissues. This calcification of the bones sets in at some definite points, mainly in the shaft of the bones and later on also at the extremities, but in between these two regions a zone of cartilage remains providing for the growth of the individual until the adult size is reached.

The bone marrow, which is the main factory of the blood cells, is found in the central cavity of the tubular bones and in the cavities of the spongy bones. Bone marrow is largely composed of fat cells lying in a tissue of large and small red marrow cells, which are the actual producers of the blood cells.

**Parts of the Skeleton.** The adult skeleton which weighs about 4 Kg. consists of 206 distinct bones. These are distributed as follows: 22 in the skull, 26 in the vertebral column, 1 hyoid bone, 3 in each ear, 24 ribs, 1 breast-bone, 4 in the pectoral girdle, 60 in the upper limbs, 2 in the pelvic girdle and 60 in the lower limbs.

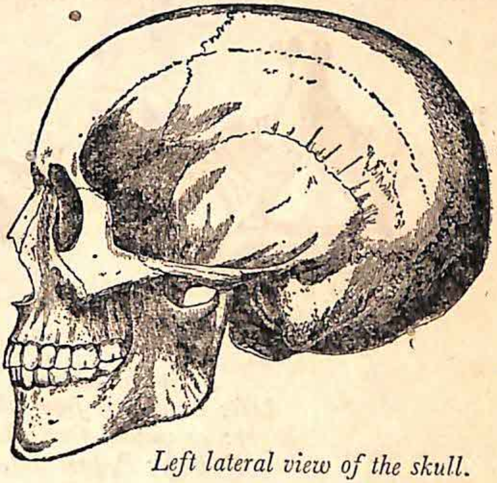
**The Skull.** The large bony case at the upper end of the vertebral column is the skull. It consists of two parts : the part above the eye-holes is called the cranium or brain case while the part below the eye-holes is called the face.

The cranium consists of 8 smooth bones. Each bone has a jagged edge like the edge of a saw and fits closely into the edge of its neighbours. The bones are thus strongly



*Anterior view of the skull.*

bound together to form an arch. This helps to make the entire cranium a very strong structure. Engineers often construct bridges in the form of a curve for they know the curved structures can be very strong. Moreover, the skull is not made up of just a single bone but of several because this arrangement makes it less liable to be broken by a sudden shock. You know that the damage done by a stone to a window consisting of just one big pane of glass is more than that done to a window consisting of many small panes of glass. It is very essential that the cranium should be one of the strongest structures in the body as it protects the brain. Damage



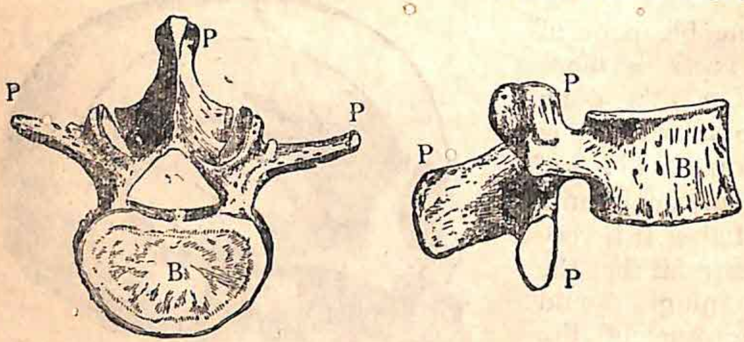
*Left lateral view of the skull.*

to the brain may result in death, paralysis or insanity.

There are 14 bones that make up the face, thirteen of which are closely bound to each other or to the bones of the cranium, while the fourteenth, the lower jaw-bone, is attached at each of its ends in such a way that it can move up and down. There are openings among the bones of the face for important organs such as eyes, nose, tongue and ears.

The hyoid bone is a U-shaped bone which lies at the root of the tongue. Although it is found in the head, it is not considered to be part of the skull. The three bones in each ear which help us to hear are also not considered to be part of the skull.

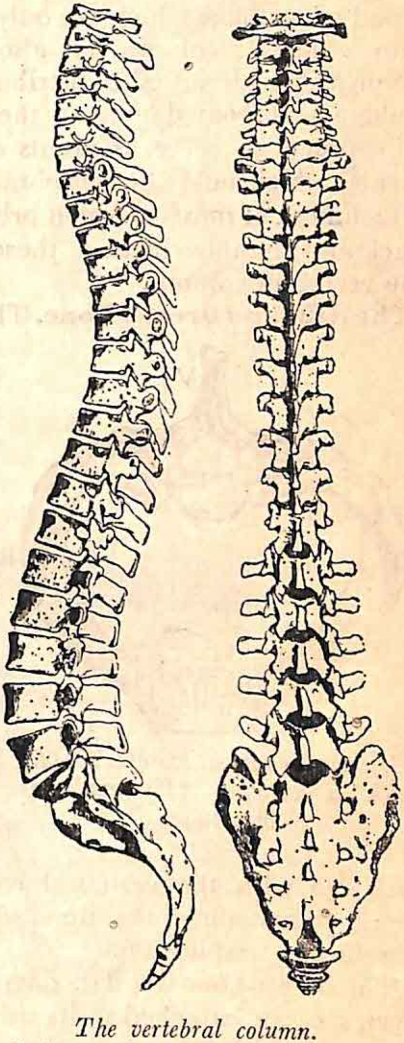
**The Vertebral Column.** This structure consists of a series of 33 irregularly shaped bones, super-imposed one on top of the other to form a curved column to which all the other parts of the skeleton are connected. The skull rests on the uppermost bones of the column while the lower bones of the column are wedged in between the bones of the pelvic girdle. The first twenty-four bones of the column forming the neck, back and loins are called movable vertebrae because they are joined to each other so that a little move-



*A typical vertebra.*
*Left: as viewed from above.*
*Right: as viewed from the side.*
*B, body; P, processes.*

ment can take place between any one of them and its neighbour. The last 9 bones of the column are called fixed vertebrae because they are fused together in two sections of 5 and 4 respectively, they are attached to each other by a joint. The column as a whole, however, is capable of wide movements. The curves of the column give the body elasticity and grace to its form.

A glance at the illustration of a single vertebra shows that in the front there is a solid body, from which spring two arches that unite to form a bony ring. The projections, called processes, are given off from the bony ring. When the vertebrae are placed one on top of the other, these bony rings form a tunnel in which lies a thick cord-like prolongation of the brain, called the spinal cord. The vertebral column thus serves to protect this delicate mass of nervous tissue.

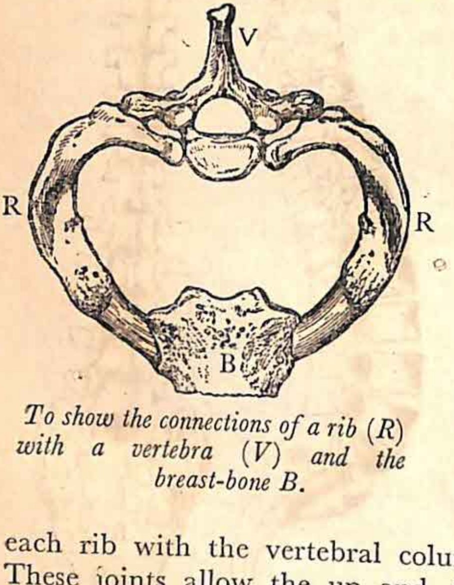


*The vertebral column.*
*Left: as viewed from the left side.*
*Right: as viewed from behind.*

The solid body of the vertebra is flat at the top and bottom. Between the solid bodies of adjoining vertebrae is a pad of cartilage which not only serves to join the vertebrae into a flexible column but also acts as a buffer or shock absorber which serves to distribute shocks and thus prevents sudden jars from damaging the all-important spinal cord. The processes serve as points of attachment for the ligaments, which hold the vertebrae together and also for the attachment of muscles which bring about the bending of the back and the movement of those bones that articulate with the vertebral column.

**The Ribs and Breast-Bone.** There are 12 ribs on each side of the vertebral column. They are curved, flat bones connected in pairs with the vertebral column at the back and, with the exception of the last two pairs, with the Breast-bone in the front. The last two pairs of ribs are called floating ribs.

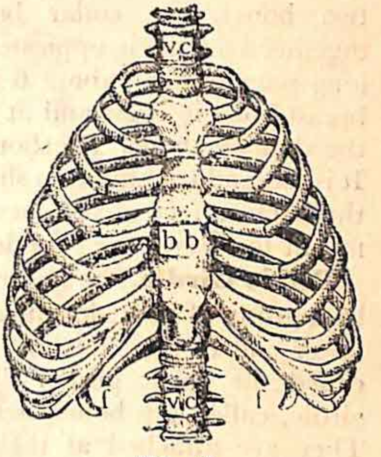
The junctions of most of the ribs with the breast-bone are made of flexible cartilage while the junction of each rib with the vertebral column is a movable joint. These joints allow the up and down movements of the ribs during respiration.



*To show the connections of a rib (R) with a vertebra (V) and the breast-bone B.*

The breast-bone is a flat, dagger-shaped bone. The first seven ribs are attached to its sides while the collar bones of the pectoral girdle are attached to its upper end.

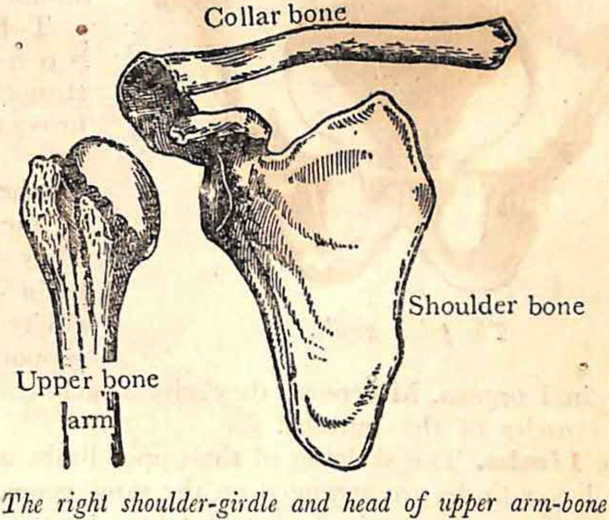
The ribs together with the breast-bone form a bony cage which protects certain vital organs in the chest such as the lungs and the heart.



*The ribs.*
*b.b., breast-bone ; f, floating ribs ; v.c., vertebral column.*

**The Pectoral Girdle.** The upper limbs are attached to the chest by a group of bones forming, very roughly, a ring around the chest at the level of the shoulders, called the pectoral girdle.

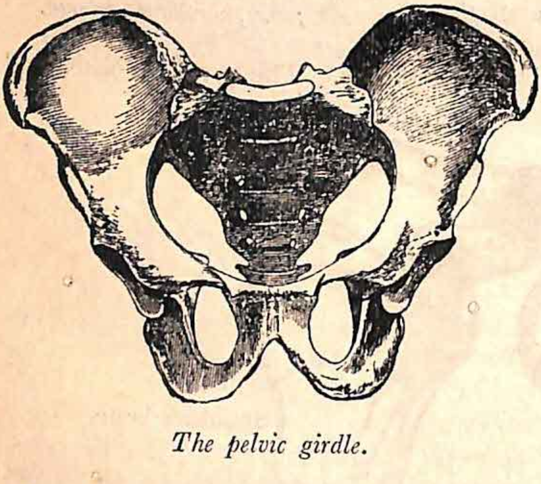
Muscles and connective tissue attach the pectoral girdle to the rest of the skeleton. Because of these flexible connections, we are able to 'shrug' our shoulders. The girdle consists of



*The right shoulder-girdle and head of upper arm-bone (front view).*

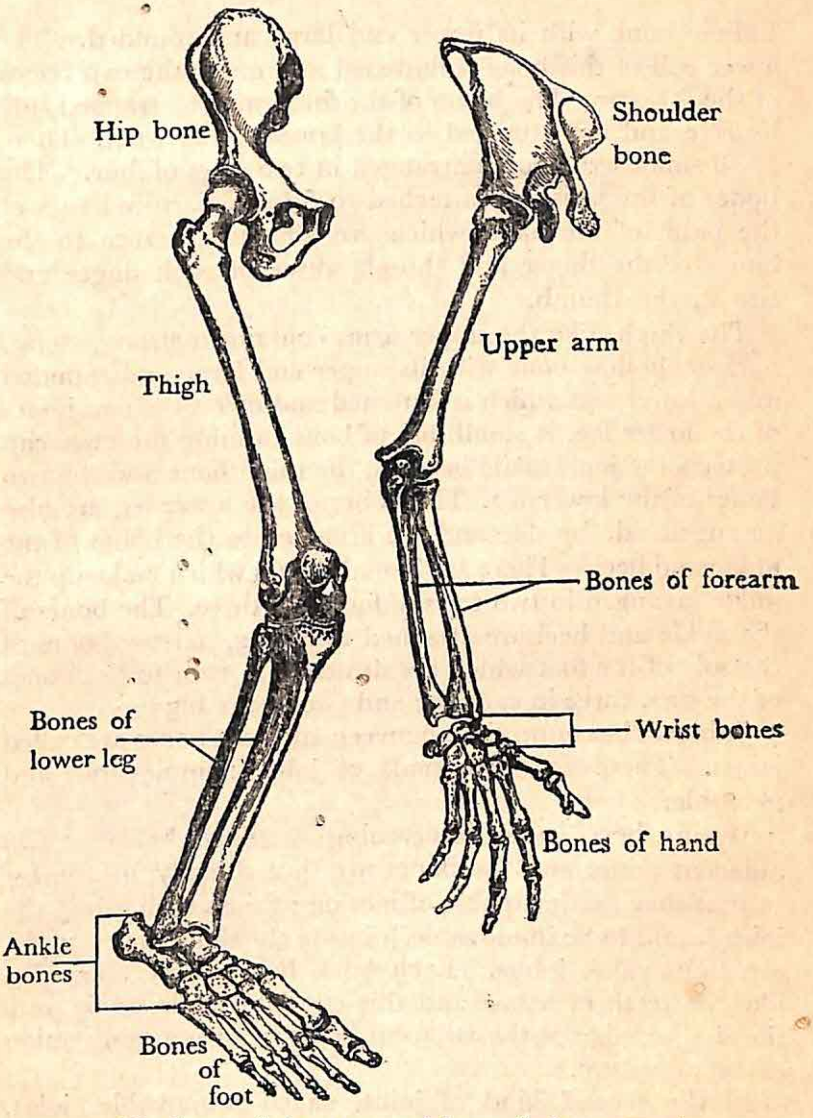
two bones, the collar bone and the shoulder bone, together with their opposite members. The collar bone is a long narrow bone about 6 in. long. It articulates with the breast-bone in front and at its other end forms a joint with the shoulder bone. The shoulder bone lies on the upper rib. It is flat and triangular in shape. Its front surface glides over the back surface of the chest. The outer end of the bone is meant to receive the rounded head of the upper arm-bone.

**Pelvic Girdle.** The lower limbs are attached to the body by a group of bones forming very roughly a ring around the lower end of the vertebral column at the level of the hip, called the pelvic girdle. The two bones comprising this girdle, called hip bones, are large and irregular in outline. They are attached at their upper ends with the lower portion of the vertebral column and at their lower ends with each other. The joints so formed are immovable. The hip bones are strong and heavy and give firm support to the weight of the body. They form a basin-shaped cavity which support the abdominal organs. Moreover, they give attachment to the large muscles of the buttock.



*The pelvic girdle.*

**The Limbs.** The skeleton of the upper limbs and that of the lower limbs are arranged on the same general plan. The upper arm contains a very strong, long, narrow,



*The bones of the upper and lower limbs compared.*

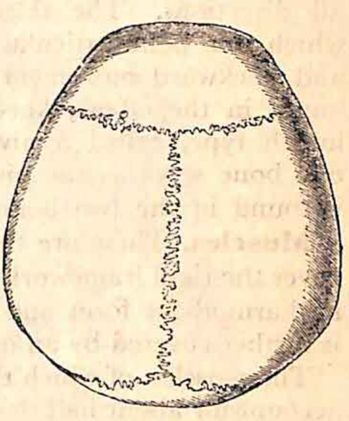
hollow bone with its upper end large and rounded. The lower end of this bone is flattened and meets the two bones of the forearm. The bones of the forearm are arranged side by side and are attached to the bones of the wrist. There are 8 small wrist-bones arranged in two rows of four. The bones of the wrist are attached to 5 long, narrow bones of the palm of the hand which are attached in turn to the bones of the finger and thumb, three in each finger and two in the thumb.

The thigh, like the upper arm, contains a strong, long, narrow, hollow bone with its upper end large and rounded and a lower end which is flattened and meets the two bones of the lower leg. A small disc of bone forming the knee-cap protects the joint made between the thigh bone and the two bones of the lower leg. The bones of the lower leg are also arranged side by side and are attached to the bones of the ankle and heel. There are 7 small bones which make up the ankle arranged in two rows of four and three. The bones of the ankle and heel are attached to 5 long, narrow bones of the sole of the foot which are attached in turn to the bones of the toes, three in each toe and two in the big toe.

**Joints.** The connections between adjacent bones are called joints. There are two kinds of joints : immovable and movable.

When there is no intervening cartilage between two adjacent bones and the bones are thus directly in contact so that they are incapable of motion against each other, the joint is said to be immovable. Joints of the skull, for example, are immovable joints. Each bone has an irregular edge like the teeth of a saw and this edge dovetails firmly into the similar edge of the adjacent bone to form a body union called a suture.

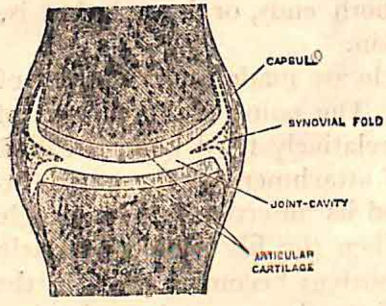
In the second kind of joint, called a movable joint, two adjacent bones are capable of motion against each other. The joint is strengthened by tough fibrous bands of



*The skull (upper view). Note the immovable joints.*

connective tissue called ligaments, which run from one bone to another and holds each in its place. Ligaments also serve to limit excess movement. One of the ligaments is thin and forms a bag around the ends of the bones called a capsule. The articulating surfaces of each bone are covered by a layer of cartilage and these layers are lined with a smooth transparent membrane as is also the inside of the capsule itself. This membrane called the synovial membrane secretes a lubricating fluid called synovial fluid into the capsule. Both the layer of cartilage and the synovial fluid serve to reduce friction between the bones to a minimum.

Four distinct types of movable joints can be distinguished in the body. The first type called a gliding joint, in which the bones slide over each other, is found in the wrist and ankle. The second type called a ball and socket joint in which the smooth rounded head of one bone rotates in the hollow socket of another is found in the shoulder where the upper arm bone meets the shoulder bone and in the hip where the thigh bone meets the hip bone. This type of joint allows movement in



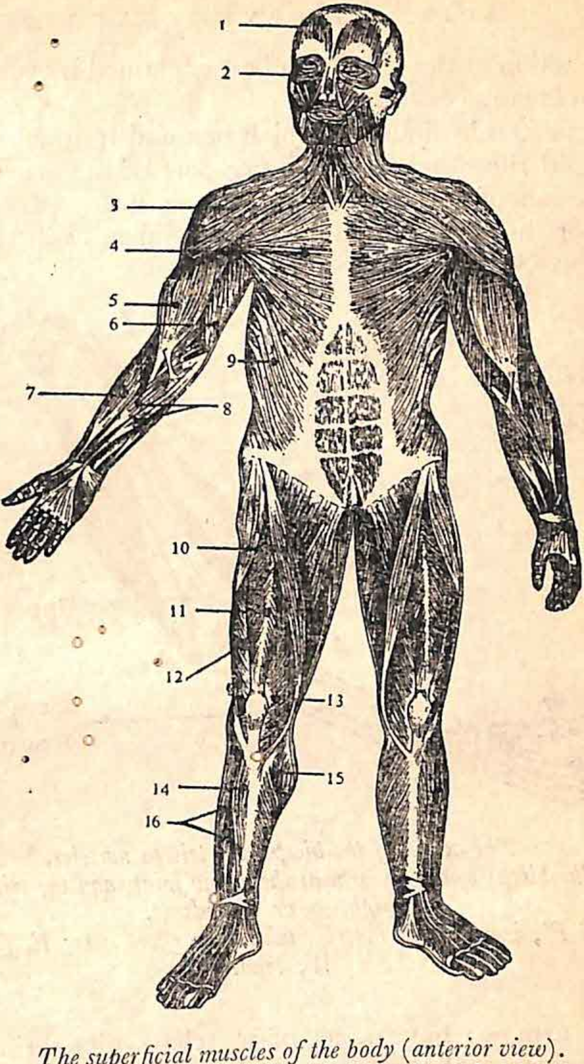
*Section showing the structure of a joint. The dotted line represents the synovial membrane.*

all directions. The third type called a hinge-joint in which one bone articulates with another so that forward and backward movement occurs like the lid of a box, is found in the elbow, knee, fingers, toes and ankle. The fourth type, called a pivot-joint in which projections of one bone serve as the pivot for the rotation of the other is found in the two bones that make up the lower arm.

**Muscles.** These are the fleshy parts of the body which cover the rigid framework of the skeleton, and give the body its harmonious form and graceful contour, the flesh itself is further covered by an outer layer called the skin.

The muscles, of which there are more than 500, normally account for about half the body weight, they are the active organs of movement of the various parts of the body and of the body as a whole. Rich in phosphorus, potassium and mineral salts, muscles consist mainly of water and of an albuminous substance called myosin. A muscle is made up of long drawn-out cells, called muscle fibres, which are arranged side by side and bound together by a membrane. Messages or impulses are brought to a muscle by a nerve. There are three kinds of muscle : voluntary, involuntary and cardiac. Voluntary muscle may be skeletal, that is, attached to bones, at one or both ends, or dermal, that is, found lying wholly in the skin.

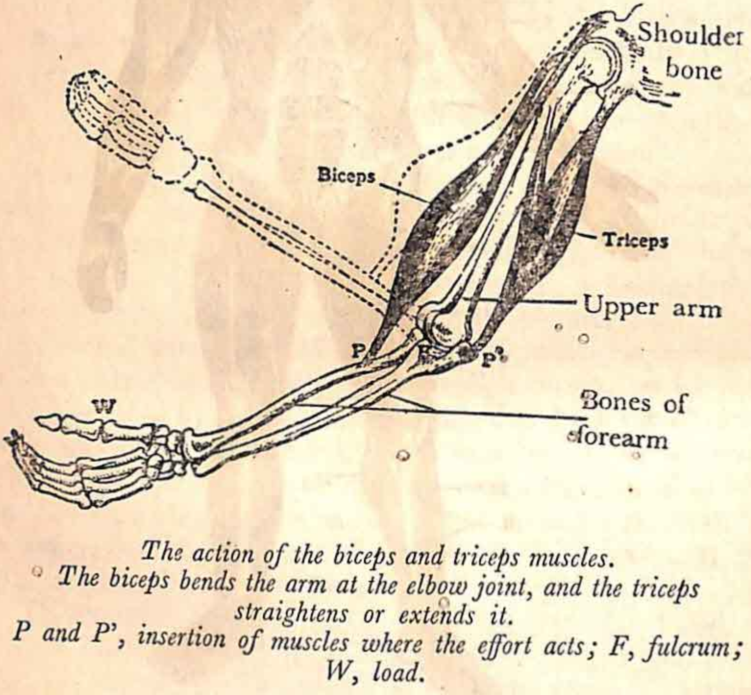
The ends of a skeletal muscle are made up of bundles of strong fibres called tendons. The point of attachment of such a muscle to a fixed or relatively fixed bone is called its 'origin' while the point of attachment of the muscle to the bone to be moved is called its 'insertion'. The muscle thus passes over a joint. When the fibres of the muscle contract, the entire muscle shortens becoming thick in the middle and the two points of attachment are brought close together. The bone is brought back to its original position by a relaxation of the muscle and also by the contraction of a second muscle on the opposite side.



*The superficial muscles of the body* (*anterior view*).
1, *wrinkles forehead;* 2, *closes eyelids;* 3, *abducts arm;*
4, *pectoralis major;* 5, *biceps;* 6, *triceps;* 7, *bends forearm;*
8, *bends wrist and fingers;* 9, *compresses abdominal cavity;*
10, *sartorius, bends knee and turns leg inwards;* 11, *quadriceps;*
12, *and* 13, *extend knee joint;* 14, *flexes and inverts foot;*
15, *gastrocnemius;* 16, *extends and flexes ankle.*

The action of the muscles is best explained by considering a few concrete examples.

The pectoralis major of which one end is attached to the chest and the other to the upper part of the arm : by the contraction of this muscle the arm is drawn towards the chest, or the chest drawn towards the arm, as in the act of climbing a tree.



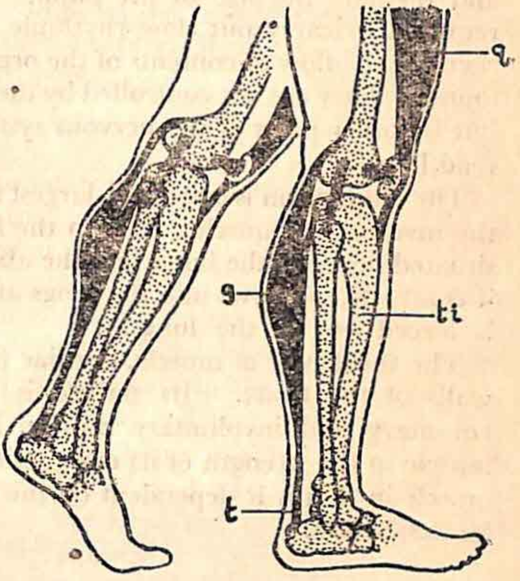
*The action of the biceps and triceps muscles.*
*The biceps bends the arm at the elbow joint, and the triceps straightens or extends it.*
*P and P', insertion of muscles where the effort acts; F, fulcrum; W, load.*

In the arm we have a set of muscles which bring about the movement of the forearm. A muscle called the biceps is placed in front of the upper arm while another muscle, the triceps, is placed behind. The forearm is raised towards the upper arm by a contraction of the biceps during which the triceps relaxes, and is brought back to its first position by the relaxation of the biceps and a contraction of the triceps.

At the back of the thigh, the hamstrings, two internal and one external (biceps), extend the hip joint and flex the leg; whereas in front, the thick muscle of the thigh (quadriceps), fixed by the tendon to the tibia, extends the knee joint.

In the lower leg, the twin muscles forming the calf (gastrocnemius) are fixed on top at the lower end of the thigh bone, and upper part of the tibia, and below by the Achilles' tendon to the heel. By their contraction these muscles lift the heel.

In the lower portions of both the forearm and the leg, there are quite a few muscles, moving respectively the fingers and the toes.



*The muscles of the leg.*
*g, gastrocnemius; t, Achilles' tendon;*
*q, quadriceps.*

The action of some of the other muscles is briefly indicated in the diagram.

All voluntary muscles are controlled by the brain and spinal cord, that is, they are under the influence of the will. They give us the power of all voluntary movements and of the maintenance of postural positions. In general, they are required to perform sudden, forcible movements.

Involuntary muscles are distributed in the walls of blood vessels, alimentary canal, iris, tracheae and in the genital and urinary systems. They control the calibre of the blood vessels, the motions of the oesophagus, stomach and intestines and regulate the size of the pupil. In general, they are required to carry out slow rhythmic movements and thus regulate the flow of contents of the organs in which they are found. They are not controlled by the brain and spinal cord but by other parts of the nervous system of which you will read later.

The diaphragm is one of the largest and most important of the involuntary muscles. It is in the form of a sheet and is situated between the lungs and the abdominal organs. When it contracts, air flows into the lungs and when it relaxes, air is forced out of the lungs.

The third type of muscle, cardiac muscle, is found in the walls of the heart. Its nature is intermediate between voluntary and involuntary muscle. It is like involuntary muscle in the strength of its contractions and like voluntary muscle in that it is dependent on the brain and spinal cord for its action.

## CHAPTER ACTIVITIES

*Outdoors*

Visit the museum and examine the various skeletons that are on display. Compare the skeleton of man with that of other vertebrates. Try to discover the connection between the general form and construction of a skeleton with the movement and way of life of the animal.

*For your wall newspaper*

Make simple outline drawings of the illustrations in this chapter and mount them on your board.

*Note-book exercises*

1. Compare the movements of the upper limbs with that of the lower limbs.

2. Read the section dealing with levers in Chapter I again. Describe how some of our body levers work. Give examples and make sketches of each of the three kinds of levers found in our body.

*At home*

1. Trace the various bones of the skeleton, feel the various muscles and locate the positions of certain prominent tendons by running your hands over your body.

2. You can prepare a skeleton of any small vertebrate by burying its body just beneath the level of the soil. After about a month remove the body from the soil, wash the bones in running water and expose them in the sun to dry.

3. Obtain the leg bone of a chicken and put it in a bottle of vinegar. Allow the bottle to stand for about two weeks. After this period you will see that the calcium phosphate in the bone has dissolved in the vinegar and a rubber-like material remains.

4. You can detect the specific action of many of the muscles in your body by moving either an arm, or a leg, or the hand, or the head, etc., and observing which muscle hardens or relaxes in the operation.

## CHAPTER XIV

# OUR FOOD, AND WHAT BECOMES OF IT

WHILE we are alive our bodies are never completely at rest. Even when we are fast asleep, movements take place continuously within our bodies. In order to move and do work we need a supply of energy. It is for this reason that we eat food. Besides providing us with energy, the heat produced when food is used is sufficient to keep our bodies warm at a fairly constant level of temperature.

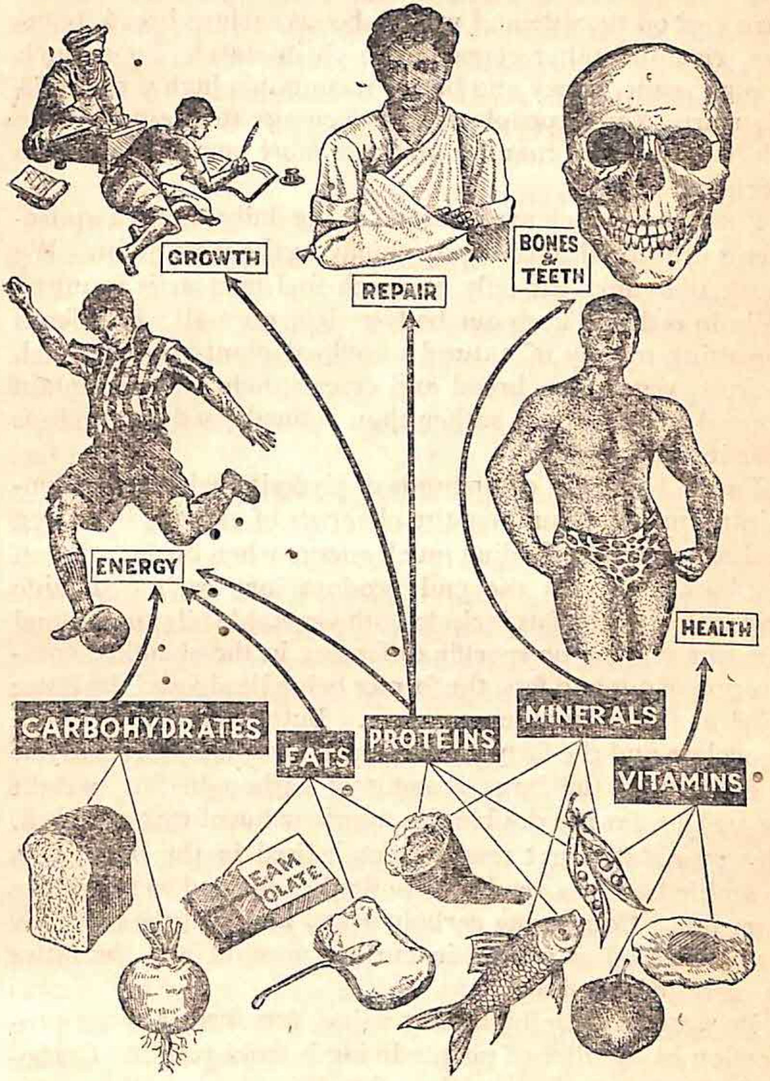
As a result of the work we do, some parts of our bodies become worn out. These parts are replaced by fresh material from our food.

Food is also required to make our bodies grow. In the case of children especially, food is used to make new material which helps them to grow.

Furthermore, certain foods contain substances which protect the body from disease and regulate its healthy working.

**Classes of Food.** Although foodstuffs are so varied as regards appearance and taste, men of science have split them up into different classes of substances. These substances have different properties and therefore different effects on our bodies. The chief classes of foodstuffs which are essential to life are : Carbohydrates, Fats, Proteins, Mineral Salts, Vitamins, and Water.

**Carbohydrates.** These are complex compounds of carbon, hydrogen and oxygen, the two latter in the same proportions as water, so that the general formula for a carbohydrate molecule is $C_m(H_2O)_n$, $m$ and $n$ being integer numbers. Substances such as sugar and starch are carbohydrates. They provide us with energy for all our activities, as well as heat to keep our bodies warm. Hence they are called fuel foods. Carbohydrate is the foodstuff which most readily gives up its energy in the organism; starch is first changed



*Food and its uses.*

into sugar, and normally the sugar is completely burnt to form carbon dioxide and water. Foods such as bread, potatoes, rice and other cereals are rich in starch. Foods such as sugar-cane, honey and beetroot contain a high proportion of sugar. Young people use more energy than adults while adults engaged in manual work use more energy than office workers.

Fuel foods which are in excess of the daily energy requirements are stored in the body chiefly in the form of fat. We must, therefore, eat only as much fuel food as is required daily in order to keep our body-weight normal. Fuel foods consisting mainly of natural unrefined plant-products such as fruit, vegetables, bread and cereals, help us to maintain normal body-weight, rather than refined products such as pastries and sweets.

**Fats.** These are compounds of glycerine with acids, containing in large numbers the elements of carbon, hydrogen and oxygen and affording much energy when burnt. When combustion occurs the end products are carbon dioxide and water. The fats include both vegetable oils and animal fats, there being no specific difference in the chemical constitution of oils and fats, the former being liquid and the latter solid at the normal temperature. Butter, cream, olive oil, chocolate and the fatty parts of meat are good sources of fat.

Because of the large amount of carbon in fats, weight for weight, fat has double the caloric value of that of starch. However, fat is not readily metabolised in the body, it is so stable hat it is readily deposited as fat and so stored for later use. Comparing carbohydrates and fats, the first may be considered as capital in current account and the latter as invested capital.

Because of their high heat value, fats form a large proportion of the diet of people living in cold regions. Carbohydrates being cheaper than fats form an important part of the diet of the poorer classes.

Muscular work plays the most important part in the metabolism of the body. In moderate work the main source of muscular energy are the carbohydrates and fats, especially the former. Experiments have shown that the output of carbon dioxide by the body increases proportionally to the work done.

**Proteins.** These are complex compounds containing mainly the elements carbon, hydrogen, oxygen and nitrogen and also sometimes phosphorus, sulphur and iron.

As you already know, proteins are intimately associated with living cell protoplams. We need proteins for body-building and for the repair of those parts of our body that have worn away. Proteins are chiefly found in all meat foods, eggs, milk and in vegetables such as peas, beans and lentils.

The protein required by the body is more or less the same for all individuals of equal size and age. Growing children and convalescents require more protein than normal adults. Generally a diet which is high in proteins and low in carbohydrates aids in keeping the figure slender. Our bodies cannot store proteins, but instead excess proteins are transformed into sugar, an energy food, and ammonia, a waste product.

Since carbohydrates, fats and proteins are fuel foods or can be converted into such, one may replace the other in an individual's diet to a considerable extent, the proportions of each varying according to the age and occupation of the individual concerned.

**Mineral Salts.** Although they do not directly contribute to the supply of energy, nor undergo metabolic change, a certain number of mineral salts play an important role in the activities of the various tissues. Without them, metabolism is not possible.

Mineral salts are required for body-building. Calcium salts are essential to form bones are teeth. Salts of iron are required for building up blood, while salts of phosphorus are needed for building up bones and nerves. All these minerals are present in an ordinary mixed diet consisting of milk, meat, fish and vegetables. Five-sixths of the total mineral matter is in the bones, these constitute an active storehouse of mineral matter on which the body can draw when the need arises.

During the summer months our bodies lose a great deal of common salt (sodium chloride) which comes out on the body surface with sweat . This substance must be replaced in order to keep the body functioning normally. Loss of salt is often the cause of nausea and heat exhaustion.

**Vitamins.** Besides the major components of the human diet, explained above, a few other substances are essential, in very minute doses, for the metabolic functions and for normal growth. Up to recent years the need of these substances, called vitamins, was not known because they are required in only very minute quantities and were present in the various natural types of food on which man was living in normal circumstances.

Vitamins are commonly distinguished from each other by a system of letters. Each vitamin is entirely distinct and unrelated to any other vitamin and, since it has its own distinctive functions, it cannot replace another in our diet. Lack of a particular vitamin from the diet gives rise to a disease called a deficiency disease. If a number of vitamins are absent from the diet the health of the individual deteriorates rapidly. On the other hand, the presence of vitamins in the diet promotes health and increases resistance to infection. A diet consisting of milk, eggs, cheese or meat or fish, butter, wholemeal and other whole-seed products, fresh fruits and vegetables ensures a full supply of all the vitamins necessary for the maintenance of good health. On account of their importance, vitamins are now prepared synthetically in laboratories and on a large scale in factories. The vitamins found in natural foodstuffs, however, are preferable to those prepared synthetically because there is always the possibility that the natural food may contain other unrecognised essentials. Also, in the case of natural foodstuffs there is no chance of overdosage.

**Vitamin A.** This vitamin is present in egg-yolk, butter, green stuffs, and in cod and fish liver oils.

A deficiency of Vitamin A in the diet lowers the resistance of the mucous membranes to infection and favours the development of inflammatory conditions of the eye, respiratory, digestive and urino-genital tracts. This in turn results in night-blindness, broncho-pneumonia, abscesses and stone in the bladder.

**Vitamin B.** This vitamin was first believed to be one vitamin, occuring in yeast and in the embryo of cereals. It has recently been differentiated into two groups of vitamins, $B_1$ and $B_2$.

**Vitamin $B_1$.** This group of vitamins is chiefly found in the seeds of all plants, especially in the embryo and to a lesser extent in the husk of the seed. It is also found in egg-yolk, animal livers, yeast, peas, beans and lentils.

Vitamin $B_1$ is required for the proper balance and nutrition of the nervous system. A deficiency of $B_1$ in the diet leads to a disease called beri-beri. In our country the mortality from beri-beri is high among people living chiefly on rice from which the outer layers have been removed by polishing. The disease affects the alimentary canal and heart, finally bringing about paralysis of the limbs and death.

**Vitamin $B_2$.** This group of vitamins is present in eggs, liver, milk and green leaf vegetables.

A deficiency of $B_2$ in the diet leads to a disease called pellagra responsible for thousands of deaths among people who live chiefly on maize and not enough on animal products. Pellagra begins with melancholia and may end in diarrhoea, various digestive disorders and insanity.

**Vitamin C.**This vitamin is present in fresh fruit and vegetables. It is destroyed by boiling.

A deficiency of Vitamin C in the diet causes a disease called scurvy which affects the teeth and the gums and also causes pains in the joints and swellings in different parts of the body. This disease was once common among sailors that spent many months away from land and so were unable to procure fresh fruits and vegetables. Infants fed on boiled or sterilised milk suffer from scurvy.

**Vitamin D.** This vitamin is generally associated with Vitamin A. It is present in the same foodstuffs as Vitamin A.

A diet devoid of Vitamin D results, in the case of children, in a disease called rickets, characterised by a softening and bowing of the bones. Exposure to sunlight has a curative effect on rickets because Vitamin D is built up in the body by the action of sunlight on certain substances in the body.

Besides the above, several other vitamins are being discovered and their specific actions are gradually determined.

**Water.** Since about 70 per cent of the total weight of the body is composed of water we can readily understand how essential it is as a food. Although it does not supply the body with energy or with building materials, it is none the less important, for none of the foodstuffs of which you have read could be used in the body without it. It dissolves more substances than any other liquid and all the soluble substances in our bodies are transported by it. The watery stream of blood distributes dissolved food substances, digestive enzymes and swills away the debris of the tissues into waste excretions such as urine, perspiration and expired air. Moreover, it serves as a medium in which nearly all the chemical changes within the body take place.

Although water is present in everything we eat and drink, yet, because we lose it continually in excretions from the kidneys, in materials that pass out from our alimentary canal, in expired air and in perspiration, we must drink large amounts of it daily so as to maintain the percentage of it in our tissues. Moreover, as the body is not able to store water as it stores fats, it is impossible to live without water for more than a few days.

**Roughage.** Our diet should contain indigestible material called roughage in order to stimulate the proper action of the muscles in the intestine. Roughage chiefly consists of the cellulose walls in the cells of plant foods which are supplied in our diet by whole-grain cereals, bread, fruits and vegetables with coarse fibres. Such materials help to fill the large intestine, and, stimulating the movements of the intestinal wall, prevent constipation.

**A Balanced Diet.** Such a diet provides in suitable proportions materials for fuel, for structure, for regulating the function of the various parts of the body and for co-ordinating and protecting the body as a whole. If anyone attempted to live on one type of food substance his health would deteriorate rapidly.

A well-balanced diet consisting of the proper food substances in the correct proportions is the basis of good health. The amount of each food substance that is necessary in the diet depends on the time of the year, the climate of the locality, the size, age and sex of the person, and the amount and nature of work in which the person is engaged. It must be understood, however, that the mere chemical composition of foods is not the only test for their nutritive value, for it is extremely important that they are palatable, easily absorbed and assimilated.

Food scientists, called nutritionists, are chiefly concerned with advising people on how to select a balanced diet. As the result of much research they recommend that in planning a day's meal, some foods from each of the five food groups as shown in the chart on page 275 should be selected. You should check your daily diet to ensure that you are obtaining all the foods necessary for good health in the proper amounts.

The lack of sufficient food substances in the diet is called malnutrition. Malnutrition is the cause of fatigue and is responsible for retarding mental and physical development. But worse than this, it makes a person easily susceptible to many ailments and diseases.

**Eating Habits.** The method of taking food, the amount eaten at a single meal, the number of meals a day, and the conditions under which the meal is taken have a direct effect on the functions of the digestive system. Food should be slowly and thoroughly masticated or chewed, before it is swallowed. If too much water is taken during meals, the food is washed from the mouth before it is properly digested by the action of the teeth and the saliva. Moreover, water dilutes the digestive juices in the stomach thus hindering digestion in that organ.

The habit of overeating is a bad practice and should be avoided. Overfilling the stomach causes inflammation of its lining which results in indigestion. If a heavy meal is taken late at night, digestion will not be complete before bedtime. Those who are in the habit of doing this frequently suffer from digestive troubles.

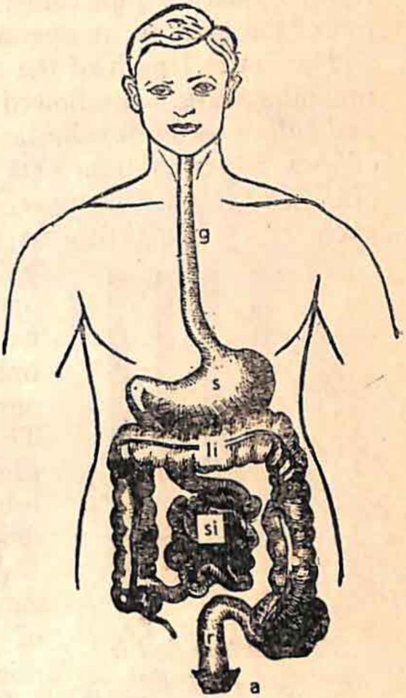
Meals should be at regular times and proper intervals between successive meals should be observed. Eating during these intervals is undesirable as it generally leads to loss of apeptite at the proper mealtime.

It is a well-known fact that at times of great emotional stress we suffer from a loss of appetite. The stomach reacts to excitement or fear by making us feel sick. Meals should therefore be taken in a pleasant atmosphere and in a contented frame of mind.

Food should be enjoyed if it is to be efficiently and rapidly digested. Well-cooked food which is attractively served and made to look appetising has more nutritive value than food which is carelessly prepared and carelessly presented. As far as possible there should be variety of food or, if this is impractical, the same food should be presented in a variety of ways.

**Digestion.** Before the foodstuffs we eat can be of any use to us it is necessary that they should be reduced to a condition in which they can be utilised. The set of processes which foodstuffs undergo whereby they are converted into substances capable of being absorbed by our bodies is called digestion. By means of this process, foodstuffs with large molecules are changed into substances that have much smaller molecules that are able to diffuse through cell membranes and also small enough to be used in forming more protoplasm.

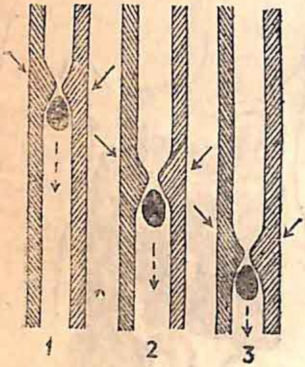
**The Alimentary Canal.** The food we eat and swallow enters a pipe called the alimentary canal. This pipe is about 30 feet long, narrow in some parts and wide in others. Although it is so long and has bulges along its length it is able to fit into our bodies as it is arranged in close coils.



*The alimentary canal.*
*g, gullet (oesophagus); s, stomach; si., small intestine; li., large intestine; r, rectum; a, anus.*

The alimentary canal begins in the mouth and is at first a narrow pipe about six inches long, spoken of as the gullet or oesophagus. This pipe runs down to a bag called the stomach. From the stomach the canal continues as a pipe which is about 20 feet long. It is called the small intestine. This in turn leads into a wider pipe about 5 feet long known as the large intestine. The last part of the alimentary canal is a short narrow pipe called the rectum. The rectum leads out of the body by an opening called the anus.

The entire length of the alimentary canal is built up of muscular walls. Swallowed food is forced along the gullet and intestines by involuntary muscular action. The walls of these pipes contract behind the food and relax in front of it. This results in a series of wave-like constrictions, called peristalsis, which keep the food moving along the canal.



*To show how food is squeezed along the alimentary canal.*

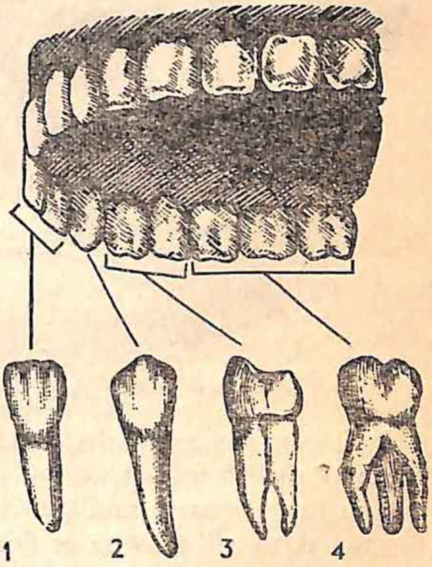
The inner lining of the alimentary canal consists of a soft, delicate skin called the mucous membrance which secretes, or gives out, a slimy fluid called mucus. This flued keeps the inside of the canal moist and also acts as a lubricant to ease the passage of food along the canal.

As the food is moved along the canal it is mixed with a number of juices. These juices contain minute quantities of substances called enzymes which help to digest the food, though they, like catalysts remain unchanged at the end.

To understand more about the wonderful way our food is broken up into suitable forms for distribution to the different parts of our body, we shall imagine that we can follow some food as it journeys along the alimentary canal.

**The Mouth.** When food is taken into the mouth it is broken up by the teeth into fragments so that it may be readily acted on by the various digestive juices. There are four kinds of teeth for this purpose. The central four of each jaw, called the incisors, are provided with sharp, chisel-like edges meant for biting or cutting the food. Next to these, on either side, is a single tooth with a pointed crown called the canine tooth. It is well adapted for tearing food. Next, beyond the canines, is a pair of teeth called the pre-molars. Behind these again are larger teeth with broad, rough surfaces called the molars. The molars and pre-molars help to grind the food.

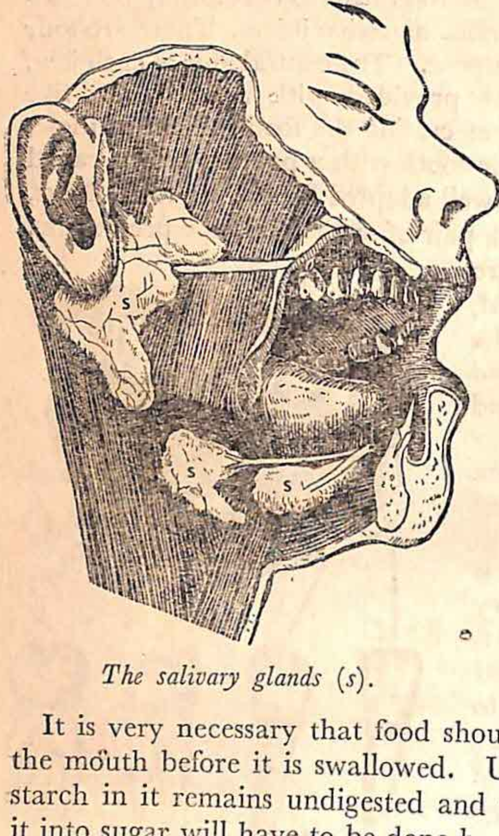
Besides being broken up by the teeth, the food is also mixed with saliva. This is a fluid which is made in the salivary glands. A gland consists of a group of special cells whose work is to produce a special kind of juice. One pair of salivary glands is situated below and in front of each ear; another pair is found underneath the jaw bone and the third pair lies just beneath the tongue. Saliva, the product of these glands, passes through tubes from the glands into the mouth. The sight, smell , or taste of food, or even the mere thought of a favourite meal is sufficient to cause the salivary glands to secrete saliva.



*Kinds of teeth.*
1. *Incisor.* 2. *Canine.* 3. *Pre-molar.* 4. *Molar.*

Saliva contains an enzyme, called ptyalin, that acts on the starch present in the food, and changes it into a form of sugar. Insoluble starch is thus changed into sugar which is soluble and therefore can be used by the body. Saliva also softens the food, making it easier to swallow.

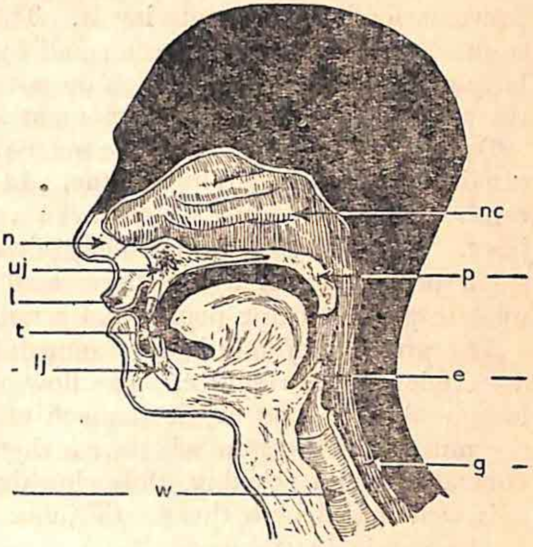
Although saliva is such an important juice, some people waste it by spitting constantly. This is a bad habit and must be avoided as it may spread germs and disease.



*The salivary glands (s).*

It is very necessary that food should be chewed well in the mouth before it is swallowed. Unless this is done the starch in it remains undigested and the work of changing it into sugar will have to be done by other parts of the alimentary canal which have their own work to do. Moreover, hard pieces of food may cause trouble in other parts of the canal and this is likely to cause indigestion.

Once the food has been prepared for swallowing, it is rolled into a ball by the tongue and forced down the throat into the oesophagus. The illustration of page 287 shows two passages going down from the mouth. The passage in front is for air and is called the windpipe, while the passage behind it is the oesophagus. During the act of breathing, the oesophagus is closed by a flap of skin which works like a trap-door, called the epiglottis. When food is swallowed, however, the epiglottis swings away from the oesophagus, opening it, and at the same time closing the windpipe. Sometimes the food gets caught in the epiglottis or gets into the windpipe, this immediately results in a fit of coughing which is the body's way of trying to dislodge whatever is causing obstruction. The food, having entered the gullet, is forced along by peristalsis.



*Longitudinal section of nose and throat. n, nostril; uj., upper jaw; l, lip; t, tooth; lj., lower jaw; w, windpipe; nc., nasal cavity; p, palate; e, epiglottis; g, oesophagus.*

**The Oesophagus.** It is a straight pipe connecting the mouth to the stomach. The passage of food through the oesophagus takes only a few seconds and no changes occur in the food.

**The Stomach.** This is a muscular bag meant for the temporary storage and partial digestion of some food. Here food may stay from one to four hours depending on its nature. During this time it is acted upon by digestive juices.

The upper end of the stomach which opens into the oesophagus is guarded by a ring-like band of muscles which prevents food from re-entering it. The lower end of the stomach which opens into the small intestine is also similarly guarded by muscles which do not allow food to leave the stomach until the proper moment arrives.

As you have already read, the inner walls of the stomach are lined by the mucous membrane. In this there are thousands of minute glands which make a juice called gastric juice. This juice, consisting chiefly of water, contains a very small percentage of hydrochloric acid and enzymes, the most important being pepsin and rennin.

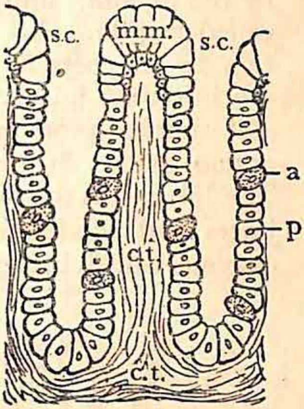
The presence of food in the stomach immediately causes a secretion of gastric juice. The flow of juice continues as long as there is food in the stomach to be digested. Now the muscles of the stomach start a rhythmic movement of contracting and relaxing, thus churning the food so that it is well mixed with the gastric juice.

The pepsin in the gastric juice cannot act on the food unless it is in the presence of hydrochloric acid. Its work is to split up the protein part of the food into soluble compounds called peptones. The rennin in the gastric juice curdles milk and helps to digest it. The hydrochloric acid assists in the digestion of proteins, kills disease germs, prevents fermentation of the stomach contents, and reacts with insoluble minerals such as calcium phosphate to produce soluble minerals.

Saliva swallowed with the food continues its action in the stomach for a short while. The moment the contents of the stomach become sufficiently acid, however, the action of the ptyalin ceases for it is destroyed by acid.

When the food has become partly digested and changed into a soft, semi-fluid mass, the ring of muscles which all this time had prevented the food from entering the small intestine, now begins to open. With every contraction of the stomach muscles a small quantity of food spurts into the intestine. After each spurt the band of muscles contracts, closing the opening.

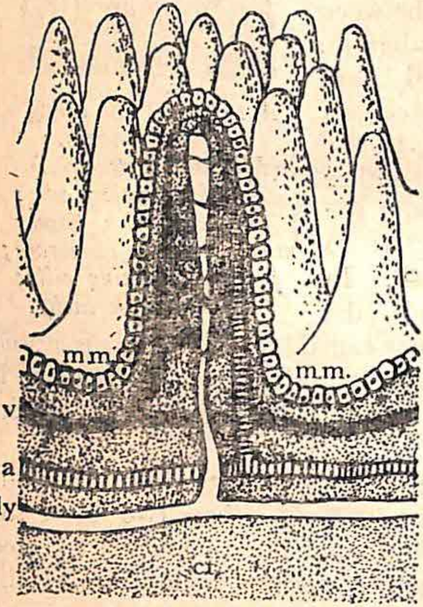
**The Small Intestine.** The first loop of the small intestine, called the duodenum, receives the partially digested food from the stomach. A tiny tube opens into the duodenum. It is formed by two tubes uniting together, one coming from the pancreas and the other from the liver. The pancreas is a large gland which is situated in the curve between the stomach and the duodenum. It makes a juice called pancreatic juice which it secretes whenever there is food in the duodenum. The liver is another gland. It lies almost opposite the pancreas in such a way as to partly cover the stomach. In addition to its other work, the liver continually makes a juice called bile. The bile is stored in a small bag known as the gall-bladder. When there is food in the duodenum, the gall-bladder gives up its contents.



*A section of the lining of the stomach.*
(*Microscopic structure.*)
*a, acid forming cells;*
*c.t., connective tissue;*
*m.m., mucous membrane;*
*p, pepsin-forming cells;*
*s.c., stomach cavity.*

The food is thus mixed with pancreatic juice and bile as it arrives in the duodenum. Besides these two juices the food is also mixed with intestinal juice which is secreted from numerous glands in the mucous membrane of the small intestine.

The first effect of these juices is to neutralise the acid mixture of partly digested food from the stomach and then make it alkaline. This immediately makes pepsin inactive as it can only act in an acid medium. The enzyme amylase in the pancreatic juice, like ptyalin, can only act in an alkaline medium and converts the starch, which escaped digestion by the ptyalin, into sugar. Another pancreatic enzyme, called trypsin, splits up the proteins, which escaped digestion by the pepsin, into peptones. An enzyme present in the intestinal juice called erepsin breaks up peptones into still simpler proteins that have smaller molecules called amino acids. It thus supplements the action of trypsin. The bile assists the digestion of the pancreatic and intestinal juices and accelerates the action of the third pancreatic enzyme called lipase which converts fats into fatty acids and glycerine.



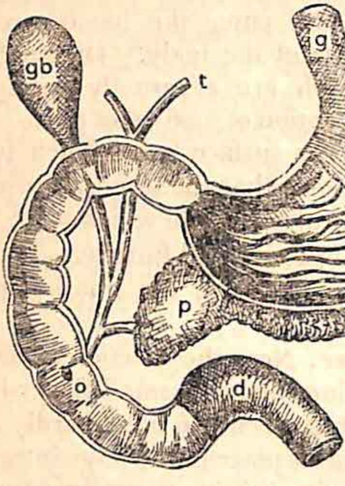
*Villi and a section through a villus.*
(*Microscopic structure.*)
*a, artery; c.t., connective tissue; l.y., lymphatic vessel; m.m., mucous membrane; v, vein.*

It takes several hours for the food to pass along the small intestine. During this time practically all the useful material in the food which has been digested is absorbed by the small intestine. The lining of the small intestine has a number of small projections, called villi (singular, villus) all over its surface. Each villus is covered by a membrane which is only one layer of cells thick. Inside the villus are tiny blood vessels which run close to the membrane. A tiny tube called a lacteal vessel lies in the centre of the villus. Digested food substances with the exception of fats, pass through the villus membrane and enter the blood stream which carries them to all parts of the body. Digested fats enter the lacteal vessels which are eventually connected with blood vessels. The absorption of food takes place very gradually and requires a large surface over which it can take place. It is for this reason that the intestine is so long and also the reason for the projecting villi which serve to increase the surface area of the intestine still further. The food that remains undigested passes out of the small intestine into the large intestine.

**The Large Intestine.** Near the junction of the small intestine with the large intestine is a small finger-like pocket called the appendix which seems to have hardly any use in the body.No digestion takes place in the large intestine.When the food arrives in this pipe it is in a very liquid state. The last remnants of nourishment together with water are now absorbed and the waste matter which remains, called faeces, gradually becomes solid. The journey of the waste material through the large intestine takes several hours. Finally it passes into the rectum where it collects until it is ejected through the anus.

It is important to get rid of this waste at least once daily, or constipation, which is the cause of much illness, will result.

**The Absorption and Fate of Digested Food.** Blood leaving the small intestine is carried by a vein to the liver.In the liver, the veins divide into capillaries. Amino acids from protein digestion and sugars from carbohydrate digestion that were absorbed by the capillaries in the villi now pass into the liver. This organ inspects or censors the absorbed food. Sugar which is in excess of body requirements is returned and stored in the liver until it is required. It is stored in the form of a starch-like substance called glycogen. Protein which is in excess of body requirements is transformed



*To show where the juices of the liver and pancreas enter the duodenum.*
*g, oesophagus; s, stomach; g.b., gall-bladder; t, tubes which convey bile from the liver; p, pancreas; o, opening of tubes from liver and pancreas; d, duodenum.*

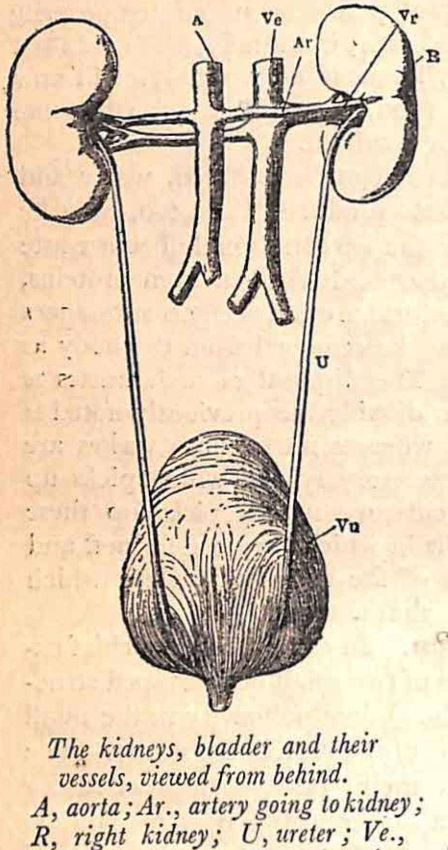
into starch and then used as fuel. Glucose and amino acids that are required by the body, however, are allowed to pass into circulation. Amino acids used as a source of energy are decomposed, ammonia being produced as a waste product. This substance is poisonous and is immediately combined in the liver with carbon dioxide and water to form urea, a harmless substance.

Glycerine and fatty acids that were taken up by the lacteal vessels in the villi reform globules of fat which pass up the lacteal vessels to a vein at the back of the neck where the substances enter the blood stream. Fat which is in excess of body requirements is stored under the skin.

**Waste and Excretion.** We have just studied the history of food in our bodies. We know now how food is digested and absorbed, how it is distributed to the various tissues, how it is modified into new protoplasm or stored temporarily as insoluble compounds and how, eventually, it is oxidised to release energy necessary for us to do work. We will now trace the course of waste products that are left when the food within living cells is oxidised.

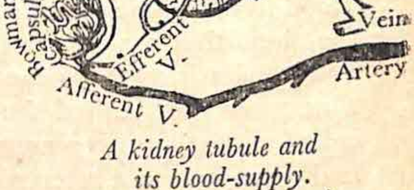
You will recall that when sugar is oxidised, water and carbon dioxide are the waste products. Fats, too, may be oxidised completely, water and carbon dioxide being waste products again. When amino acids derived from proteins, are oxidised, the waste products are nitrogenous substances which being poisonous must be removed from the body as soon as they are formed. The disposal of such wastes is called excretion. Carbon dioxide, as previously noted is disposed of by the lungs, whereas nitrogenous wastes are disposed of by a special excretory system which picks up waste materials. The circulatory system picks up these wastes from the various cells in which they are formed and brings them to the organs of the excretory system which are concerned with their elimination.

**The Organs of Excretion.** In our bodies, the chief excretory organs take the form of two small bean-shaped structures situated just outside the abdominal cavity in the small of the back, one on each side of the vertebral column. The kidneys are arranged with their concave surfaces facing each other. Each kidney is a vast collection of over a million tubules. Three vessels enter the kidney at the longitudinal depression in its concave surfaces. The first of these is an artery which springs from the aorta and conveys oxygenated blood to the whole organ; the second is a vein which collects the blood that has circulated in the capillaries of the kidney and carries it away to the inferior vena cava; the third is a narrow tube, called the ureter which removes the fluid called urine that was secreted by the kidneys from the blood and conveys it to a reservoir called the bladder. The artery



*The kidneys, bladder and their vessels, viewed from behind.*
*A, aorta; Ar., artery going to kidney; R, right kidney; U, ureter; Ve., inferior vena cava; Vr., vein going to kidney; Vu., bladder.*

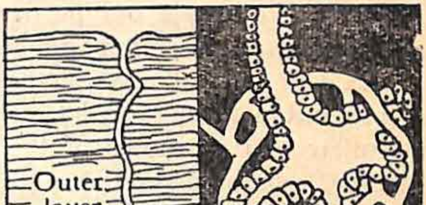
that enters the kidney breaks up into many tiny vessels, which, as they take blood to the kidney tubules, are called afferent vessels. Each of these vessels enters a cup-shaped cavity at the end of the tubule called a Bowman's capsule, where it gives rise to a cluster of capillaries called a glomerulus. The capsule communicates with the rest of the tubule which after running a tortuous course in the body of the kidney unites with other tubules to form collecting ducts which empty their contents into the ureter. Blood is carried away from a glomerulus by a vessel called an efferent vessel which in due course empties its contents into a vein. Nitrogenous waste substances, chiefly urea, uric acid and various other salts filter from the blood



*A kidney tubule and its blood-supply. (Microscopic structure.)*

plasma through the capillary walls of the glomerulus and enter the cavity of the capsule. The solution formed by these substances in water is known as urine. This fluid passes down the ureter to the bladder where it is temporarily stored. At the proper time, the bladder, which is under control of the nervous system, discharges its contents to the outside by another tube called the urethra.

Excretion of wastes also takes place through the skin. As you will recall there are countless sweat pores on the free surface of the skin. These pores are the openings of tiny ducts which lead to sweat glands situated in the deeper portion of the skin. As the ducts pass through the skin they are twisted like a corkscrew, while in the glands they are coiled up into little balls. Each sweat gland is surrounded by a dense network of capillaries. As the blood circulates through these capillaries, the cells of the gland separate a fluid called perspiration or sweat from the blood and pass it up the duct to the surface of the skin from where it evaporates and in doing so cools the skin. Perspiration consists mainly of water in which sodium, chloride and other salts are dissolved. From the function which



*A cross section of part of the skin.*
*(Microscopic structure.)*
*Inset: a sweat gland with capillaries entangled around it.*

has been described, one must regard the skin as an excretory organ. The lungs , too, must be looked upon as excretory organs as they are concerned with the elimination of carbon dioxide and water in the form of water vapour from the body. The large intestine, however, is not considered to be an excretory organ because it eliminates substances that have never been part of the body, such as indigestible food.

## CHAPTER ACTIVITIES

*Outdoors*

Visit the museum. Make a comparison of the teeth of herbivorous, carnivorous and omnivorous animals.

*For your wall newspaper*

1. Make simple outline drawings of the illustrations in this chapter and mount them on your board.
2. Cut out coloured pictures of different kinds of foods from old magazines, and arrange them to make a food chart similar to that shown of Pg. 275
3. Prepare coloured bar graphs to show the percentage composition of various foodstuffs. The following figures will help you to do this.

| *Foodstuff* | *Carbohydrate* % | *Fat* % | *Protein* % | *Minerals* % | *Water* % | *Roughage* % | *Vitamins Present* |
|---|---|---|---|---|---|---|---|
| Milk | 5.0 | 4.0 | 3.0 | 0.7 | 87.0 | — | A, B, C, & D |
| Butter | — | 82.0 | 1.0 | 5.0 | 12.0 | — | A & D |
| Cheese | — | 32.0 | 30.0 | 3.0 | 35.0 | — | A |
| Lean beef | — | 5.0 | 20.0 | 3.0 | 72.0 | — | A, B & C |
| Fish | — | 0.6 | 22.6 | 0.8 | 78.4 | — | A, B & D |
| Fowl's eggs | — | 10.0 | 15.0 | 1.0 | 74.0 | — | B & D |
| Whitebread | 51.0 | 1.0 | 7.0 | 1.0 | 40.0 | — | |
| Potatoes | 18.5 | 0.5 | 2.0 | 0.5 | 78.5 | — | A, B & C |
| Rice | 77.0 | 0.5 | 6.0 | 0.5 | 16.0 | — | B |
| Wheat | 71.2 | 1.5 | 11.8 | 1.5 | 12.0 | — | A & B |
| Cabbage | 6.0 | — | 1.5 | 1.5 | 90.0 | 1.0 | A, B & C |

*Note-book exercises*

Consult books in your science library, and collect material for an essay on 'Milk—the perfect food'.

*At home*

1. When we swallow our food it does not simply fall down the gullet, but is squeezed along by peristalsis, a muscular action over which we have no control. You can prove that this is so by a simple experiment.

Lay a cushion on the floor next to the wall and stand on your head. Try eating a biscuit in this position. The food you swallow is pushed along against the force of gravity and goes up to your stomach.

2. Starch is converted into sugar in the mouth by the action of an enzyme called ptyalin which is present in the saliva. If you chew a piece of bread you will find that although at first it does not taste sweet, yet at the end of about half a minute it tastes quite sweet.

3. Place a tightly fitting bottle or test-tube over one of your fingers. After some time you will notice that the inside surface of the bottle becomes misty. Can you say why?

4. Make a list of foods you eat in a single day and say what classes of foodstuffs they contain.

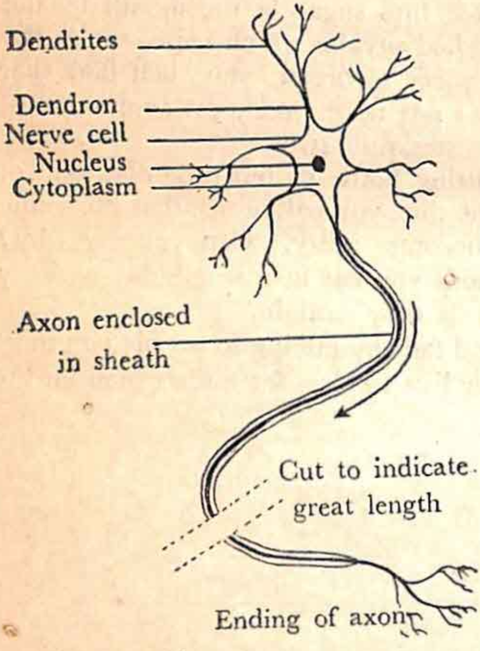
5. Make a list of food fads by talking to people you meet about food. Bring your lists to class for a discussion on the subject.

## CHAPTER XV

# OUR NERVOUS SYSTEM

THE nervous system initiates and regulates almost every movement of the body. It directs and controls the various systems and keeps them all working together in harmony with each other for the good of the whole body.

The nervous system may be likened to a telephone system with the brain doing the work of a great central telephone exchange; the groups of nerve cells in the spinal cord acting as local exchanges, while nerve impulses (messages) are carried by the nerves which may be likened to telephone wires connecting every part of the body either directly or indirectly to the brain.



*A nerve cell.*
*(Microscopic structure.)*
*Arrow shows the direction in which the message is sent.*

**Structure of the Nerves,** A nerve cell consists of a tiny mass of protoplasm from which fine elongated threads of protoplasm called nerve fibres branch off. A nerve cell together with its fibres is called a neurone. Many of these fibres are short while only one is long. The short fibres are called dendrons and they branch into a number of smaller nerve fibres called dendrites. The long fibre called the axon does not branch into smaller fibres except at its end. It proceeds from the body of the nerve cell to some specific structure such as a gland, a muscle or another nerve cell. The protoplasm of the nerve cell has the property of irritability to an extreme degree while the nerve fibres connect this highly irritable protoplasm with various other body cells. Dendrites carry impulses towards the cell body while axons carry impulses away from the cell body. We will read later in the chapter how nerves transmit impulses.

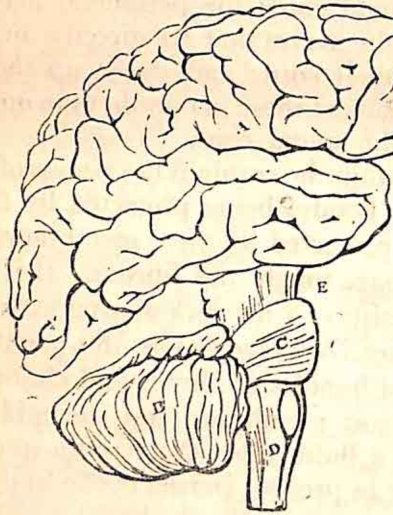
**Parts of the Nervous System.** The nervous system may be divided into the central nervous system which consists of the brain and spinal cord; the peripheral nervous system which consists of the nerves that are directly connected with the brain and spinal cord; and the sympathetic nervous system which consists of those nerves that are only indirectly connected with the spinal cord.

**The Brain.** Within the cranium lies a mass of nerve tissue called the brain. Besides being protected by the cranium, the brain is also protected by three membranes; the outermost is very strong, tough and fibrous, the innermost is vascular and consists of a network of arteries and veins supported by connective tissue, while the membrane in the middle consists of bundles of fibrous and elastic tissue. Between the innermost membrane and the middle one is a space filled with a fluid called the cerebro-spinal fluid that serves as a buffer to prevent jarring of the brain consequent on violent movements of the body.

The nerve cells constituting the brain are arranged so that the cell bodies form the outer surface, often described as 'grey matter', while the remainder of the brain is made up of the nerve fibres from these cells and is referred to as 'white matter'. The actual colour of the brain, however, is pinkish on account of the large number of blood vessels that ramify among the nerve cells. All the work of the brain is done by the cell bodies, while impulses are transmitted by the fibres.

The brain is hollow and the cavities within it are called ventricles. These cavities are continuous with the central cavity in the spinal cord called the central canal. The ventricles and the central canal are filled with lymph.

You will notice from the illustration of the brain that its surface is drawn into a number of folds or convolutions. It is evident that, since all the nerve cells are situated at the surface, more of them will be accommodated by an increase in the number and depth of the convolutions. It is



*The human brain (right side). The parts are represented as separated from one another somewhat more than is natural so as to show their relation better. A, cerebrum; B, cerebellum; C, pons; D, medulla; E, mid-brain.*

generally believed that an intelligent individual has more convolutions in his brain than a dullard.

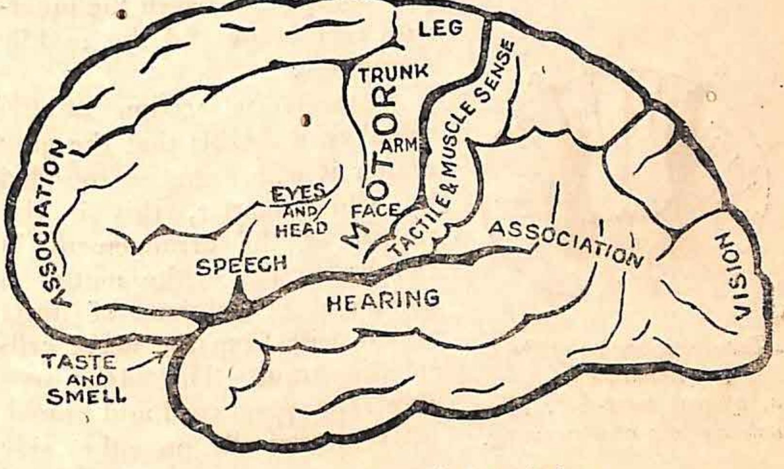
The brain is divided into four chief regions: the cerebrum, the cerebellum, the pons and the medulla.

The cerebrum is deeply grooved in the middle and divided into two halves, called hemispheres. It receives messages which enter into and form our consciousness. It is the chief seat of intelligence, memory, volition, emotions and sensation.

The cerebellum co-ordinates muscular movements and presides over the mechanism of balance. Damage to the cerebellum often results in a peculiar staggering gait.

The pons is the conducting medium between cerebrum, cerebellum and medulla. Four of the twelve pairs of cranial nerves that take their origin from the brain originate from the pons.

The medulla is connected with the pons above and with the spinal cord below. It is thus ideally placed for conducting impulses between the brain and spinal cord. It presides over involuntary movements such as the acts of breathing and heart beat, and regulates the calibre of

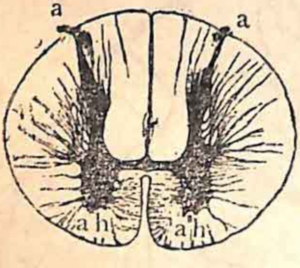


*'Map' of the left cerebral hemisphere.*

the smaller arteries. It is readily understood therefore that any damage to the medulla results in instant death.

**The Cranial Nerves.** There are 12 pairs of nerves connected with the brain. They are concerned with the conveying of impulses to and from the brain. Impulses from the various sense organs are passed along some of these nerves and such impulses reaching the brain are transformed by it into sensations. For example, an impulse sent along one of the cranial nerves, say the optic nerve, is sent to that part of the brain concerned with sight, and if this part is healthy and trained to interpret the impulse, the individual sees and understands what he sees.

**The Spinal Cord.** The long cylinder of nerve tissue contained within the vertebral column is the spinal cord. The hollow space in the middle, called the central canal, is continuous with the ventricles of the brain. The spinal cord is about 18 in. in length and nearly as thick as the little finger. It extends from the medulla to the base of the vertebral column. Like the brain, it is enclosed and protected by three membranes. The fluid buffer which prevents jarring of the brain serves the spinal cord in the same way and occupies the space between the innermost membrane and the middle membrane.



*Transverse section of the spinal cord.*
*a, afferent nerve-root; a.h., anterior horn of grey matter.*

A transverse section of the spinal cord reveals that the grey matter is within and surrounded by white matter, this is the reverse of the arrangement in the brain. The white matter is composed of columns of fibres which arise from the nerve cells in the brain. The fibres pass down the spinal cord and branch off symmetrically on either side of the vertebral column throughout its entire length. They leave the spinal cord through apertures between the vertebrae. There are thus 31 pairs of spinal nerves.

The nerve cells constituting the grey matter of the spinal cord are seen in a cross section of the spinal cord to resemble somewhat the letter H. These cells relieve to some extent the work done by the nerve cells of the brain. Especially when immediate action is required to protect the body from injury, it is these cells which send impulses to the muscles to perform the necessary action. Such action is called reflex action and you will read about it shortly.

**Afferent and Efferent Nerves.** Nerve fibres which convey impulses to the nerve cells of the central nervous system are called afferent nerves, while those that convey impulses away are called efferent nerves. Sensory and motor nerves are examples of these two classes of nerves. Nerve fibres which convey impulses from the skin or a sense organ to the nerve cells of the central nervous system are afferent nerves and since these impulses arouse sensations of touch, sight or hearing they are called sensory nerves. Nerve fibres which convey impulses from the nerve cells of the central nervous system to the muscles are efferent nerves and if these impulses cause the muscles to contract they are called motor nerves. Nerve fibres such as the spinal nerve fibres which contain both sensory nerve fibres and motor nerve fibres are called mixed nerve fibres.

**The Function of Spinal Nerve Roots.** Each spinal nerve, since it has both afferent and efferent fibres, has two roots. Look at the illustration showing a cross-section of the spinal cord. The lower ends of the letter H from which a bundle of efferent nerve fibres pass outwards is the efferent root of these fibres and it is here that the cell bodies of these fibres are located. The upper ends of the letter H into which a bundle of afferent fibres pass is the afferent root of these fibres. Each afferent root has a swelling on it called a ganglion formed by a collection of the cell bodies of these fibres. Each cell body in the ganglion gives off just one fibre which divides into two portions, one of which extends into the grey matter of the cord while the other joins the axones of the efferent neurones to form the spinal nerve.

**Functions of the Spinal Cord.** The spinal cord is the medium by which sensory and motor impulses are conveyed to and from the brain. It is also a centre for reflex actions.

If the spinal cord is severed or injured at any point, all power of voluntary movement and sensation is lost to every part of the body that is supplied by nerve fibres which arise from below the level of injury. This is because the impulses received by the sensory nerves cannot pass from the spinal cord to the brain and moreover no volunatry movements of the parts concerned are possible as motor impulses can no longer pass downwards.

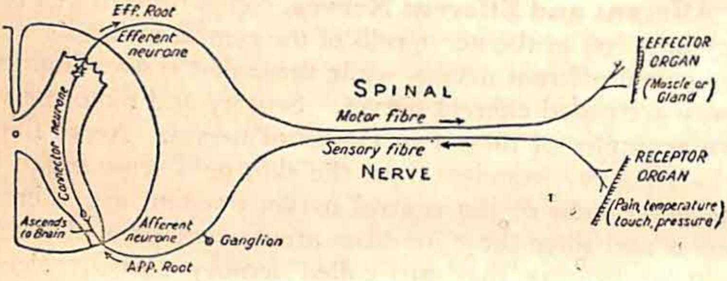


*Diagram of a spinal nerve and its roots.*

**Reflex Acts.** These are movements produced by the spinal cord or brain without the action of the will as the result of sensory impulses brought to it. For example, when the soles of the feet in a sleeping person are pinched, tickled or otherwise irritated the legs are suddenly drawn up before he becomes aware of what has happened. The tickling, or whatever stimulates the nerve-endings and activates the nerves, is called the stimulus while the skin is said to be the receptor organ. The stimulus applied to the receptor organ causes sensory impulses to pass from the receptor organ up the afferent fibres of the nerves through their afferent roots and into the grey matter of the spinal cord which is a centre for receiving such impulses. These impulses act on the grey matter of the spinal cord so that they cause new impulses to arise, called motor impulses, which pass from the grey matter of the spinal cord through the efferent root by the efferent nerve fibres to the muscles of the leg and foot which, as they contract and thus bring about movement, are called effector organs. The muscular contractions and the movement which results is called a response. A reflex act takes place very fast, impulses travelling along nerve fibres at the rate of 120 metres per second, so that it takes a small fraction of a second for the transmission of an impulse from the receptor organ to the effector organ.

The reflex act described above is produced to a certain extent without the action of the will or brain. If the spinal cord is cut or damaged, that is, its connection with the brain is destroyed, the reflex act described can still take place thus proving that the centre for this reflex act is in the spinal cord.

Many of the movements we perform are instances of reflex acts. When a strong light is suddenly flashed into our eyes we instantly close them; if we unintentionally touch a hot object with the hand we instantly withdraw the hand; if someone touches us from behind we turn around to see who it is; when we see an appetising dish our mouth begins to 'water'. In the first instance, the brain is exclusively concerned in the reflex act. In the second instance, the spinal cord alone is concerned in the reflex act. In the third instance, the reflex act is not carried out by the spinal cord alone, but by the intervention of the brain as well. In the fourth instance, an afferent impulse reaching the brain, by reflex action gives rise to an efferent impulse which is not a motor impulse, but a secretory impulse as it causes the salivary glands to secrete saliva. Some movements, such as walking, are begun by the action of that part of the brain concerned with volition, that is they start as voluntary acts, but are continued as reflex acts in which the muscles concerned contract and relax because of receiving motor impulses from the central nervous system that are regulated and are in accordance with sensory impulses received by the central nervous system from various sense organs. Breathing movements are further examples of involuntary movements that are performed or modified by reflex action.

In almost all reflex acts, the brain exercises a controlling influence and limits the violence of the movements produced. Moreover the brain can prevent or limit to a definite degree the motor impulses sent in response to a sensory stimulus. With reference to our previous example it is possible by an effort of the will to prevent the foot being jerked away when the sole is irritated.

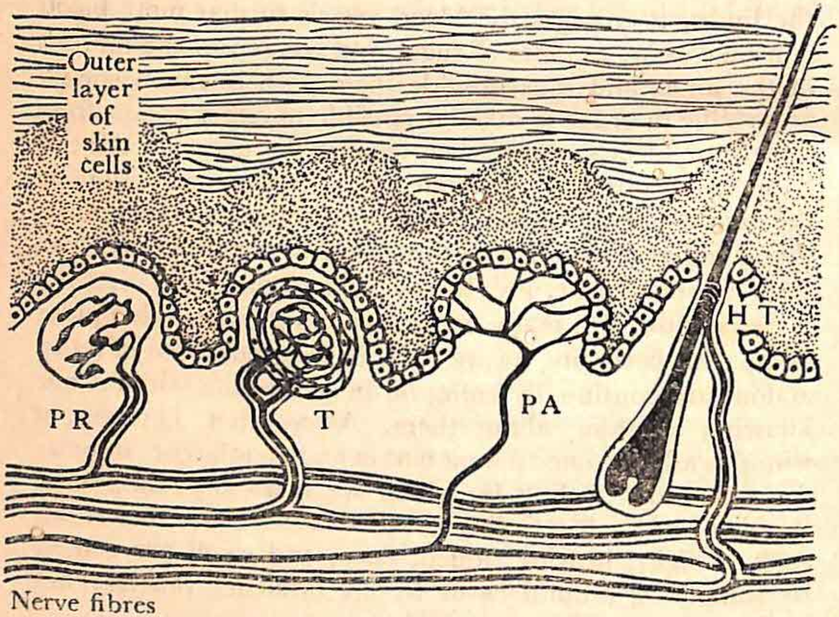
**The Sympathetic Nervous System.** Soon after the spinal nerves pass out of the vetebral column they give off a small short branch which connects them to a row of ganglia lying along each side of the front of the vertebral column. The ganglia are connected together by nerve fibres. The chains of ganglia so formed running from the skull to the pelvic girdle, together with their branches, constitute the sympathetic nervous system. From each chain the nerve fibres for the most part follow the blood vessels and pass to the abdomen and chest, where they form great networks upon the heart and abdominal organs. Nerve fibres also pass from each ganglion into the spinal nerves and also into some of the cranial nerves. The sympathetic nervous system is thus closely connected to the central nervous system. The nerves belonging to the sympathetic nervous system are chiefly concerned with carrying impulses which govern the action of involuntary muscles such as the muscular tissue of the internal organs and the muscular coats of the small arteries that supply the various tissues. The nerves of this system also control the production of secretions from certain glands.

Ordinarily, we have no conscious control over the sympathetic nervous system. During an emergency, this system takes complete control of our body and helps to defend us from danger. At this time it transmits impulses to the liver to send an extra-supply of sugar into the blood, it increases the rate of breathing, it accelerates the action of the heart, it stops digestion so that the blood required by the muscles of the alimentary canal may be diverted to the limbs, it enlarges the blood vessels so that more blood can take extra supplies of sugar and oxygen to the muscles in the limbs and thus provide them with as much energy as possible in order to make it possible to either escape from danger or to defend ourselves against the enemy. All this happens very quickly without any thought or decision by the brain. Some of the actions controlled by the sympathetic nervous system are the result of emotions we feel, such as anger, fear, joy, sorrow and so on.

**Sensation.** On many occcasions, a reflex act takes place without us becoming aware of it. In fact, hundreds of reflex actions are continually going on in our bodies without our knowing anything about them. Very often, however, a stimulus affects our afferent nerves and an afferent impulse gives rise to a feeling by which we learn that something is going on. Such a feeling is called a sensation. Sensations such as sight, hearing, touch, taste, and smell are caused by something around us or by an influence that reaches us from our environment.

The body is equipped with three separate parts to produce a sensation. There is firstly, the receiving apparatus known as the receptor organ, secondly, nerve fibres which carry impulses to the brain and thirdly, the brain (cerebrum) which translates these impulses into a state of consciousness. Specialised receptor organs are adapted for special sensations, such as sight (the eye), hearing (the ear), smell (the nose) and taste (the tongue). General sensations such as uncomfortableness, restlessness, faintness, hunger, thirst and fatigue are felt by the body generally and very seldom reach a level of consciousness, and when they do they are vague , undefined and of a generalised nature.

**Cutaneous Sensations.** Any portion of the body which is supplied with sensory nerves may be considered in a restricted sense to be an organ of touch. The sensation



*Section of the skin to show nerve endings.*
*HT, nerve attached to hair and sensitive to touch; PA, organ of pain; PR, organ of pressure; T, organ of change of temperature.*

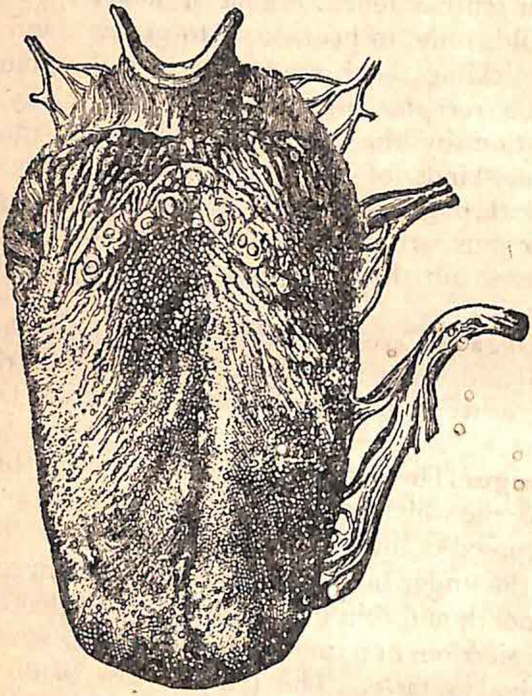
of touch may be classified besides the sensation of touch proper into sensations of pain, temperature, pressure and those which are known as muscular sense by which we become acquainted with the condition of contraction of our muscles.

The skin is studded with nerve endings which provide us with our sense of touch. Some of these respond to pain, some to cold, some to heat, some to pressure and some to itching or tickling. Each kind of nerve ending must be regarded as a receptor organ, since it is specially adapted to stimulation by the appropriate environmental factor. The various kinds of receptor organs are not equally distributed throughout the skin. For example, the touch receptor organs are most numerous at the tips of the fingers, less so on the chest and hardly any on the back of the body.

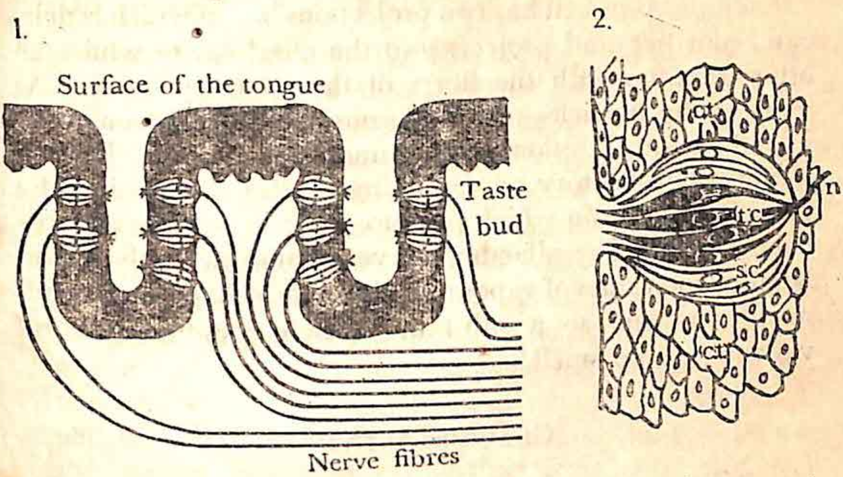
**Sense Organs.** We have already dealt with the eye in Chapter 3 and we will deal with the ear in the next book. Here we will describe the organs of taste and smell.

**The Tongue.**The organs of taste lie embedded in the mucous membrane which covers the tongue and palate.The tongue is composed of muscles and covered by a mucous membrane.On the under surface of the tongue the mucous membrane is smooth and thin but its upper surface has a number of raised projections or papillae which make the tongue rough and sensitive to taste. The papillae are richly supplied with receptor organs for taste called taste buds. These organs are small oval bodies that lie embedded in the surface of the skin covering each papilla. Each taste bud has an outer layer of cells. From one end of each of these cells a small delicate hair-like thread of protoplasm projects into the mouth. When this thread comes into contact with food the other end of the cell, through the sensory nerve connected to it, conveys the taste impulse to the brain. For a substance to be tasted it must be in solution.

The taste buds are concerned with four kinds of taste: sweet, bitter, sour and salt. The taste buds at the tip are most sensitive to sweet substances, those at the back to bitter, while those at the sides most readily respond to sour substances. Besides taste, however, we have sensations which are described as flavours that are really sensations of smell.

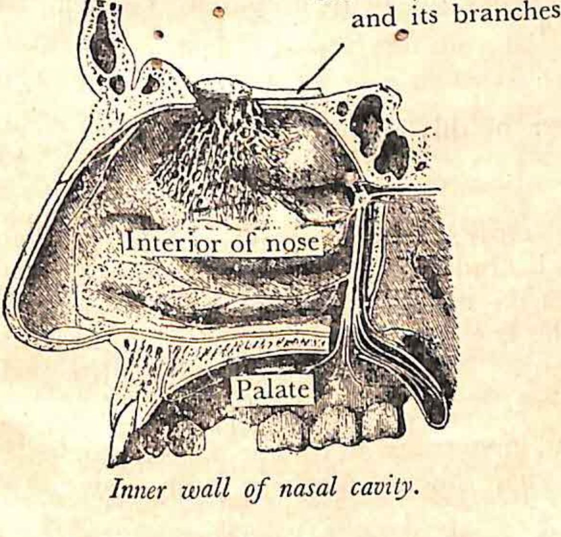


*Upper surface of the tongue.*



1. *Section through the surface of the tongue (microscopic structure).* 2. *A taste bud (microscopic structure).* *c.t., connective tissue; n, nerve; s.c., supporting cells; t.c., taste cells.*

**The Nose.** The nostrils lead into the nasal cavities, the upper parts of which are lined by a delicate mucous membrane which constitutes the organ of smell. The receptor cells of these organs are supplied by nerve fibres from the main nerve concerned with the sense of smell called the olfactory nerve. This nerve is a cranial nerve.



*Inner wall of nasal cavity.*

Each receptor cell has two projections one of which is delicate, hair-like and projects into the nasal cavity while the other ramifies with the fibres of the olfactory nerve. As soon as the particles of an odorous substance become dissolved in the secretions of the mucous membrane they stimulate the olfactory nerve endings and a sensory impulse passes to the brain which interprets the impulse as a particular smell. The olfactory nerve endings are only stimulated by molecules of vapour reaching the cells of the mucous membrane and so a substance which does not give off vapours has no smell.

## CHAPTER ACTIVITIES

*Outdoors*

Visit the butcher's shop and obtain a fresh sheep's brain. Compare it with the picture of a human brain given in this chapter.

*For your wall newspaper*

Mount on your board the maps prepared as under 'At home' No. 3 and 4.

*Note-book exercise*

Make a summary of this chapter.

*At home*

1. Sit down and cross the right leg over the left so that the left knee fits in behind the right knee-joint and the right leg hangs freely. Strike the right leg with the edge of your hand just below the knee-cap. Note that the left leg jerks forward and upward. This is a reflex action and is called the 'knee-jerk' reflex.

2. You have read in your text that some parts of the body are more sensitive than others. You can easily prove this

by means of the following experiment. Obtain a pair of dividers and open them so that the points are half a centimetre apart. Gently touch the back of a friend's neck with the points. Ask him to guess how many points are touching his neck. He will probably answer 'one'. Widen the points and repeat the experiment. Ask him now to close his eyes and repeat the experiment on his finger tips, on the palm of his hand, on the tip of his tongue, on his back and on various other parts of his body. The nearer the two points of the dividers which are distinctly felt as separate points, the more sensitive to touch is that part of the body. You will find that in the case of the tongue the two points of the dividers can be felt as distinct from each other when the distance is only one millimetre, while on the back of the body the distance must be about 7 cm. before they are felt separately. From this it follows that the tip of the tongue is about 70 times more sensitive than the back of the body.

3. Blindfold a friend and mark out an area of 50 sq. cm. on the back of his hand. Divide this area into sides of 1 cm. Map out the 'cold spots' and the 'hot spots' as follows. Take a metal tube and fill it with ice-cold water. Touch each square lightly with the bottom of the tube and mark those squares at which the sensation of cold is most strongly felt with red ink. Repeat the experiment with fairly warm water in the tube. Mark those squares at which the sensation of heat is most strongly felt with blue ink. Now ask your friend to repeat the experiment with you as the subject. Compare the two maps thus made. You will find that different parts of the skin vary in their sensitivity to heat and cold and that the exact positions of the cold and hot spots vary in different individuals.

4. Blindfold a friend and touch different parts of his tongue with lime juice. Repeat with table salt, epsom salts, soda and quinine. Make a map of his tongue to show the

parts of it which are sensitive to acid, saltness, sweetness and bitterness. Ask him to make a map of your tongue showing these parts in the same way. Compare the two maps.

5. Grip your nose so that you cannot smell, and try eating a banana. You will find that it is tasteless. Take your fingers away from your nose and you will find that you can 'taste' the fruit. This is because the senses of taste and smell work very closely together so that you cannot tell them apart.

THE END

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